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FLIGHT TESTS OF A LOW-COST OMEGA NAVIGATION RECEIVER.(U)
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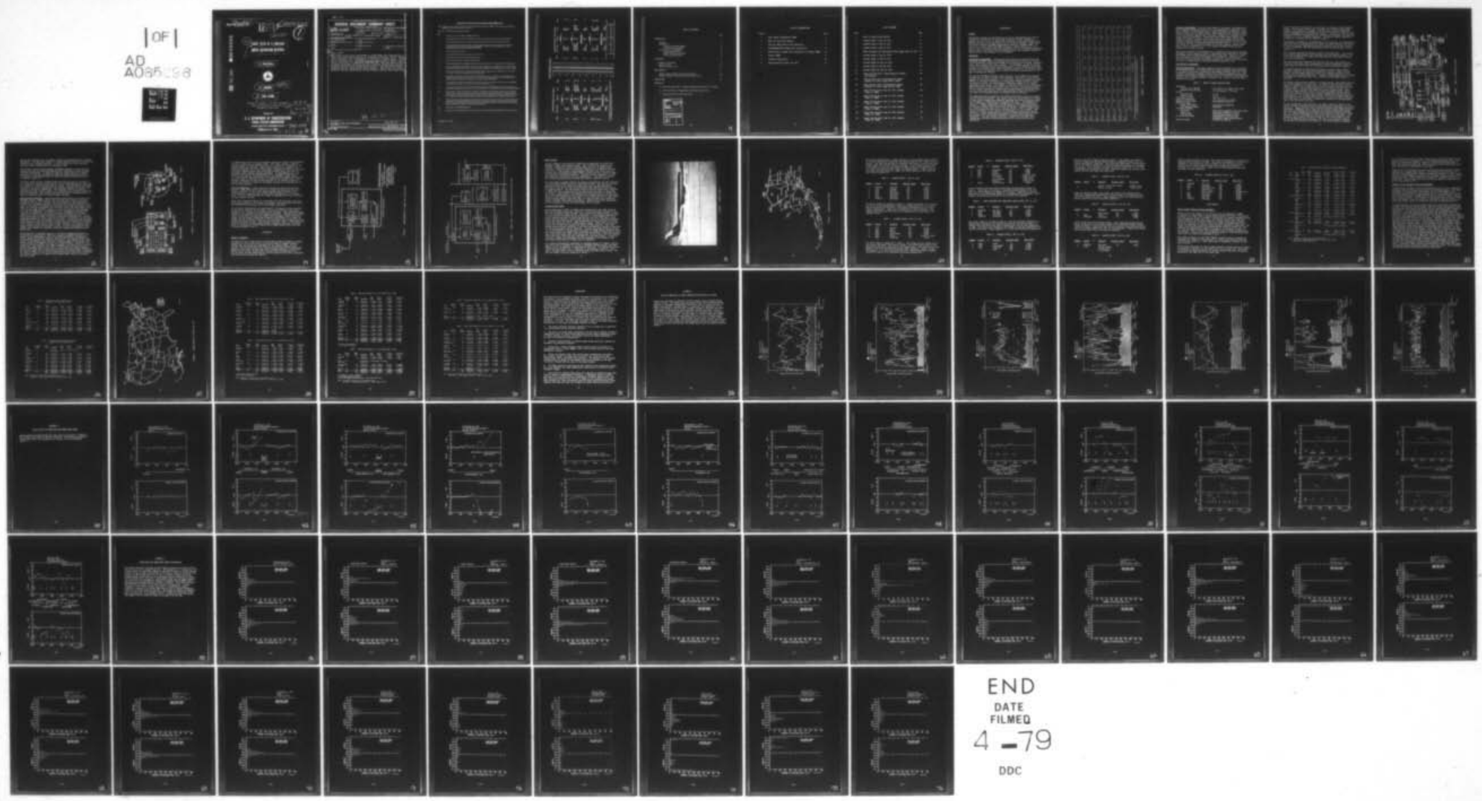

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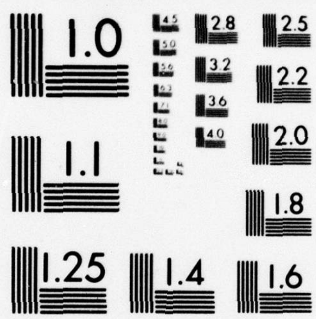
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(10) Robert Moore

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Washington, D.C. 20590

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This report

Describes flight tests performed to investigate the feasibility of using low-cost Omega avionics for enroute navigation, and to assess Omega navigation as a supplement to VOR/DME in remote areas. Tested was a prototype Mark III Omega receiver, developed by Dynell Electronics, Melville, NY. Results indicate that low-cost Omega avionics provides acceptable guidance during quiescent propagation periods. Flights during diurnal transition periods of the day would require compensation for anticipated phase changes. There were no indications of terrain sensitivity at the minimum enroute altitudes flown.

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16. KEY WORDS FOR INDEXING

VOR-DME; Very Low Frequency (Doc Des--P)

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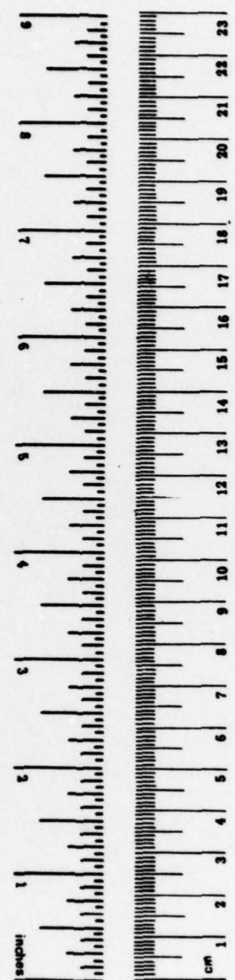
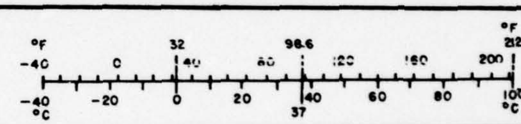
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

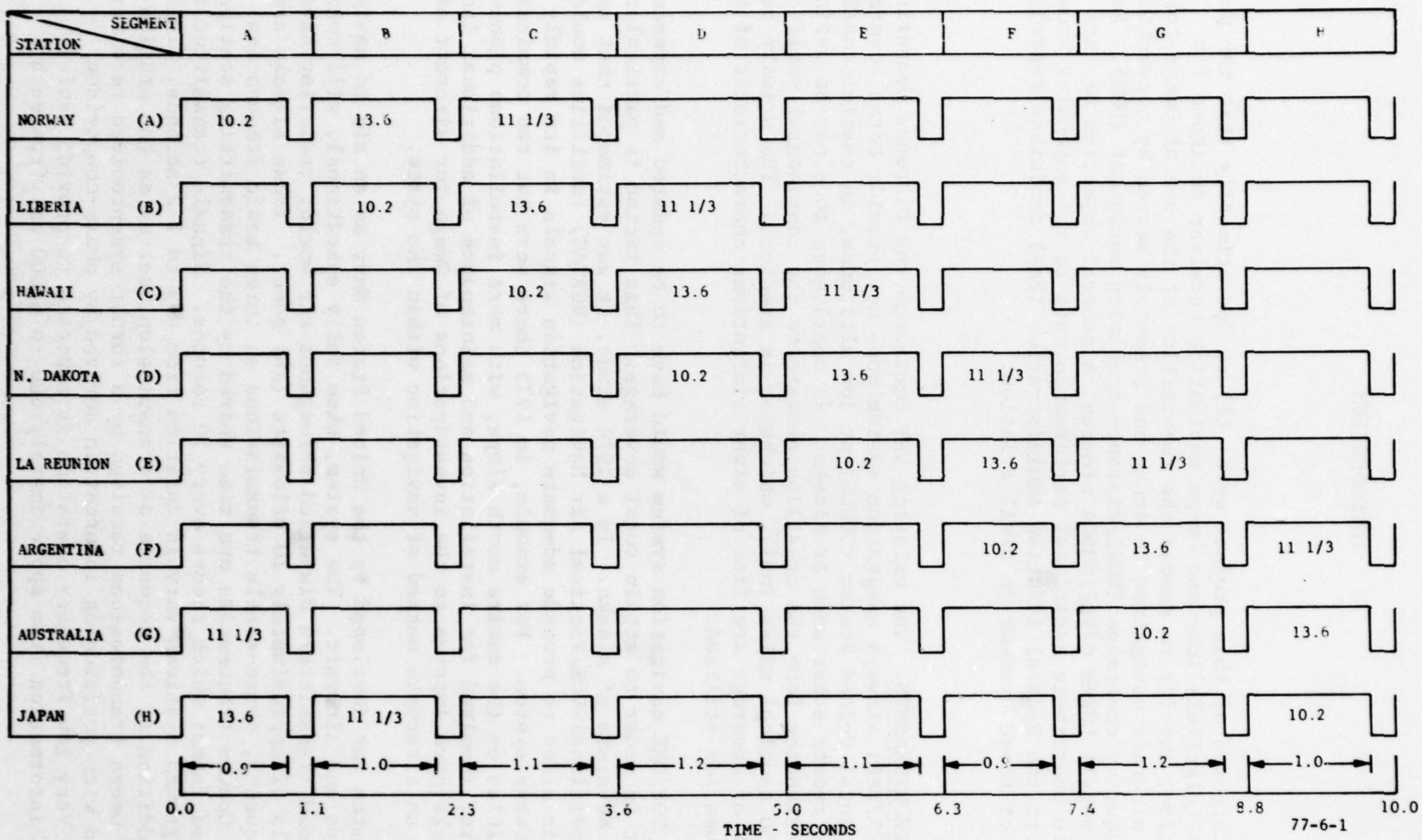
The primary purposes of this project were: (1) to operationally test the performance of a relatively low-cost Omega navigation receiver designed for general aviation, and (2) to assess the feasibility of the use of Omega transmissions for aircraft navigation in areas not presently served by conventional very high frequency omnirange (VOR)/distance measuring equipment (DME). As part of the overall LORAN C/VLF/OMEGA program, a general objective of this project was to contribute additional performance data to the expanding knowledge base to support the Federal Aviation Administration (FAA) decisions regarding applications of these systems in civil aviation.

BACKGROUND.

OPERATIONAL REQUIREMENTS. The existing VHF Omnirange and Distance Measuring Equipment (VOR/DME) airways navigation system does not provide total coverage in the Continental United States (CONUS) at low altitudes, in coastal confluence zones, and in remote areas such as Alaska. (A confluence zone may be defined as the area extending from the coastline seaward to the continental shelf (100 fathoms) or 50 nautical miles (nmi), whichever is greater.) The primary reasons for this lack of coverage are line of sight limitations characteristic of the band of frequencies utilized.

The existing VOR/DME navigation system would have to be updated and expanded at great cost in order to attain total coverage. This factor is particularly apparent in the state of Alaska. In a 1974 study, it was estimated that approximately 26 additional VOR/Tactical Air Navigation (VORTAC) facilities would be required in order to provide adequate navigation signals in its rapidly expanding airways system. For example, in 1975 there were but two commissioned VORTAC facilities on the entire north slope, with more installations planned. The cost factor involved for installation and maintenance of additional facilities in Alaska gave impetus to the investigations of Omega for aircraft of all types as an alternate method of navigation within the state.

The Omega system was developed by the United States Navy as an aid to navigation for ships and aircraft. The system, when fully operational, will consist of eight ground transmitters dispersed throughout the world, radiating navigational signals of approximately 10 kilowatts (kW) power. These signals are very low frequency, phase-stable transmissions on three basic frequencies (figure 1). Common frequencies are time shared by the transmitting stations in a specified format which recurs every 10 seconds. Signals transmitted by the various ground stations vary in duration from 0.9 to 1.2 seconds. This factor, in addition to the sequence of transmission, serves as the station identifier. Omega transmissions received by a format-synchronized receiver, are processed with positioning information derived by phase-comparison techniques. Very low frequency operation is expected to provide useful navigational information from approximately 600 to 6,000 nmi from each transmitter.



NOTES: TRANSMISSION FREQUENCIES (kHz) ARE NOTED WITHIN THE SEGMENTS ASSIGNED.
BLANK SEGMENTS ARE RESERVED FOR UNIQUE FREQUENCY ASSIGNMENTS.

FIGURE 1. BASIC OMEGA TRANSMISSION FORMAT

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TECHNICAL REQUIREMENTS. From the early 1960s to the present, the Omega worldwide navigation system has evolved from a few experimental transmitters to an almost completely standardized chain of dedicated navigation stations. Signal characteristics such as radiated power, phase stability, and reliability have varied and gradually improved over the years, largely due to advances in technology gained by experience. By the same token, Omega signal sensors have ranged from simple, stationary monitoring receivers to highly sophisticated complete navigation systems. Data collection instrumentation has also varied from pencil and pad to digitized computer-compatible devices. It can be said that masses of data have been collected for various purposes (timing, ionospheric studies, navigation, etc.) in an Omega environment which has been changing for the past 15 years.

This report describes the performance of a prototype low-cost general aviation navigation receiver during a series of tests which were conducted in the Omega environment which existed between July 1974 and May 1975. Basically, these tests consisted of a series of flights in the vicinity of Atlantic City, New Jersey during quiescent and diurnal periods and a series of flights within the state of Alaska during a relatively quiescent period of time.

DESCRIPTION OF EQUIPMENT.

OMEGA NAVIGATION SET. The Omega navigation receiver employed for testing was an engineering model of the Dynell Mark III Omega navigation system developed by the Dynell Electronics Corporation, Maxess Road, Melville, New York. This equipment represented a minimal concept of an airborne navigation system and provided only guidance information to the pilot in the form of course deviation indication and a digital display of distance to go. Table 1 lists the specifications of the set.

TABLE 1. MARK III OMEGA SPECIFICATIONS

Dimensions	
Receiver Unit (DR-30)	6 in wide x 3 in high x 13 in deep
Indicator Unit (DI-30)	3.5 in diameter x 5 in deep
Weight	
Receiver Unit	4.5 lb
Indicator Unit	1.5 lb
Prime Power (Total)	+12 V d.c. 1A
Operating Temperature	-20° Celsius (C) to +60°C
Maximum Aircraft Speed	Approximately 400 knots
Navigation Range	
Single Leg Flight	Approximately 1,000 nmi
Multiwaypoint Flight	Unlimited
Navigation Readouts	
CDI Meter	Sensitivity nominally 4 nmi full scale
Miles to Go	Three-digit display to 99 nmi
To/From Flag	Indicates destination arrival
On Ground Setup Time	Approximately 2 minutes with destination number predetermined
Antenna Coupler	Provided as required

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The set consists of three units: (1) receiver, (2) indicator, and (3) antenna coupler. The receiver accepts only the primary 10.2 kilohertz (kHz) Omega frequency, for simplicity of design. This unit also contains thumb-wheel switch programming and synchronization functions. The indicator unit provided guidance information and provisions for zeroing the crosspointer and inserting a distance to go for a desired flightpath. The antenna coupler supplied was designed for a standard E-field long-wire antenna.

Functionally, the Omega set is subdivided into six sections: (1) radiofrequency (RF) front end, (2) synchronizing and timing, (3) signal detection and identification, (4) signal tracking and automatic frequency control (AFC) section, (5) lane accumulator, data and readout generators, and (6) operator controls (figure 2).

The RF section contains the antenna, coupler, and preamplifier. Its function is to amplify Omega signals and to minimize noise and unwanted signals. The output of this section is an amplified square-wave 10.2-kHz signal suitable for further processing.

The synchronizing and timing section develops precision timing pulses and reference clock signals which synchronize an internally-generated Omega time-frame signal with the actual 10.2 kHz Omega station transmission sequence.

The signal detection and identification section contains signal envelope detection threshold, and pulse width measuring circuitry. These circuits identify received Omega signals by either of two methods depending on the position of the synchronizing switch. Automatic synchronization of the internally generated time-frame signal with a validly received Omega signal is available.

The signal tracking section consists of a phase detector, weak-signal detector, and storage registers for phase data. The phase of each 10.2 kHz received signal is compared by the phase detector to an internally generated 10.2 kHz reference signal. The resulting phase data are stored at the end of each reception until 10 seconds later when the station transmits again. This enables the phase detector circuit to be time multiplexed and thus permits tracking of signals received from all Omega transmitting stations with one phase detector. As the weak-signal detector compares the internal Omega time-frame signal and the 10.2 kHz received signal, it generates signal-to-noise data (S/N) which is thresholded to produce an indication on the weak-signal lamp if the S/N ratio is too low.

The lane accumulator, data generator, and readout generator consist of two 12-bit, up/down accumulators (one for each station-pair selected) and a vector subtractor. These circuits process destination-minus-origin Omega coordinate information (thumbwheel switch inserted) and present position-minus-origin data (from the accumulators) to produce destination-minus-present position data as a sign-plus-magnitude for each line of position (LOP) chosen. These data are fed into the arithmetic unit and the miles-to-go generator. The arithmetic unit produces the error voltage for the course deviation meter and the TO/FROM flag control voltage. The miles-to-go generator supplies the distance information to the indicator. The course generator supplies

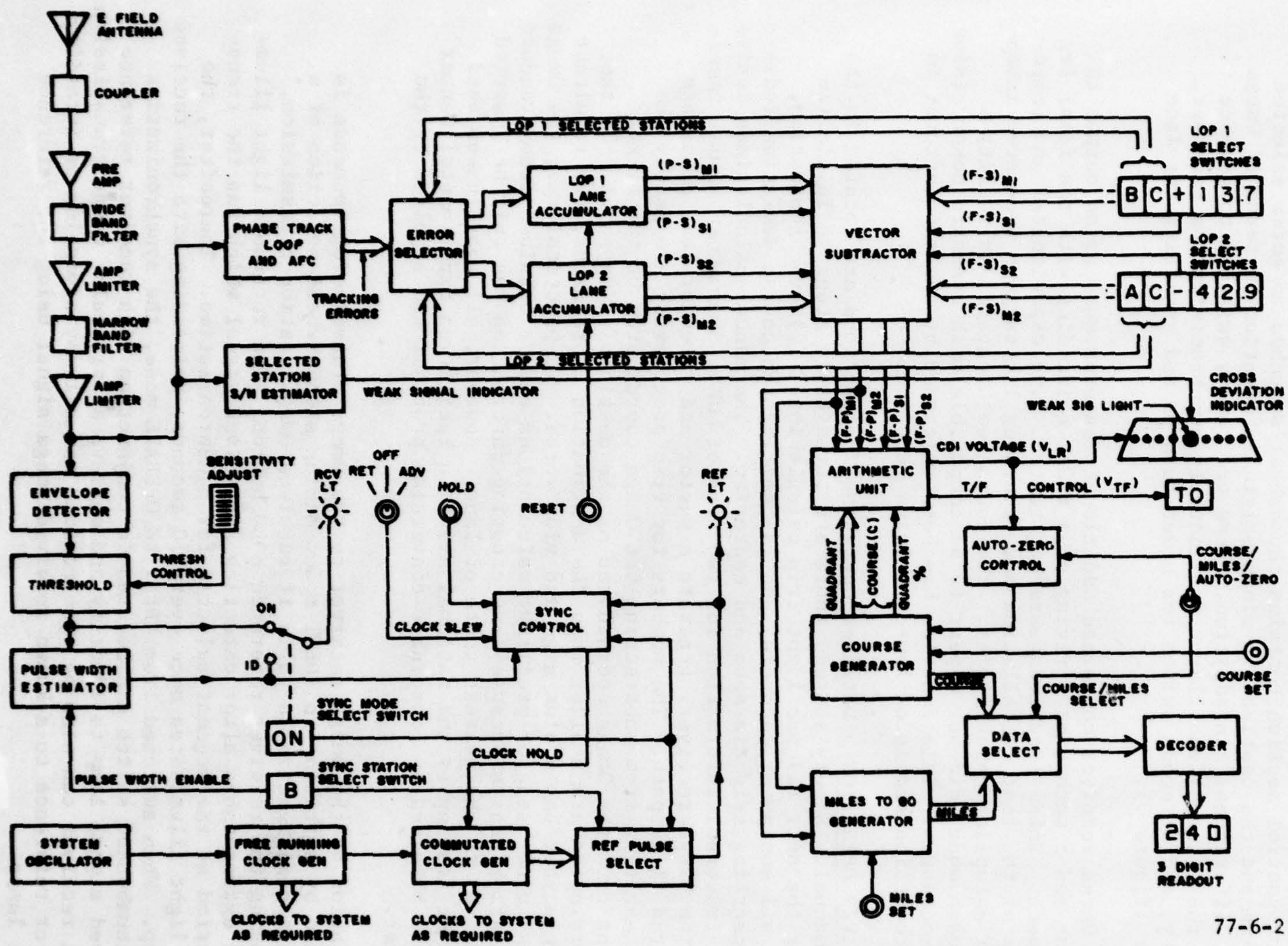

FIGURE 2. MARK III FUNCTIONAL DIAGRAM

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data to the arithmetic unit to produce correct lane crossing rates for a given destination. The indicator (figure 3) contains readout circuitry for displaying the miles-to-go course information. It also contains the course deviation indicator (CDI), TO/FROM flag, and weak-signal lamp.

The operator control section contains thumbwheel switches to enter selected station pairs and the destination-minus-origin information in terms of Omega coordinate differences. In addition, there are rotary switches to advance and retard the internal oscillator for manually synchronizing the receiver, if necessary, and a second switch for power turn-ON and resetting the lane accumulator (figure 3).

The Dynell Omega receiver contained additional features such as an output to an autopilot and a method of arriving at a track coinciding with the final leg of an approach. These functions were not tested. The experimental and temporary nature of the test installation and recording limitations prevented investigation of autopilot capabilities. The course-set feature, in reality a quasi-approach mode, did not appear to be compatible with standard nonprecision approach procedures. This function has been discarded by the manufacturer in later preproduction models of low-cost Omega receivers.

OMEGA RECEIVER OPERATION. Detailed operating instructions are located in the equipment manual. Simply stated, there are three basic steps to initialize and operate the set: (1) preflight trip calculations, (2) synchronization, zeroing of all equipment counters, and (3) setting the course deviation indicator by inserting trip distance and centering. The manual calculations derive Omega lane traversal information for two sets of LOP's, and after manual insertion into the Omega receiver, generate a vector and rates of lane crossings for a desired flightpath. The numbers for trip programming are merely the remainder resulting from subtracting the Omega coordinates of the flight origin point from the Omega coordinates of the destination/waypoint. If the origin coordinates are smaller than the destination coordinates, the resultant programming number has a plus sign and vice versa. In practical use, the Omega coordinates to be used for preflight calculations can be obtained from standard Omega navigation charts because lane crossing information can only be inserted in the receiver to the nearest tenth of lane. However, all coordinates used during flight testing by the National Aviation Facilities Experimental Center (NAFEC) were obtained by coordinate conversion programs and supplied by the manufacturer.

Synchronization of the Omega receiver to the Omega transmission sequence is accomplished by switching to IDENT mode, making a thumbwheel selection of a segment letter designating a valid if received Omega station transmission, and depressing the receiver reference HOLD button. The reference light illuminates and extinguishes after detecting a received signal which has the transmission period at the segment selected for synchronization. Thereafter, the reference light illuminates once every 10 seconds, coinciding with the received signal lamp. When switched from IDENT to OPERATE mode, the synchronization selector thumbwheel switch can be used in conjunction with receiver reference and received signal lamp to identify and observe a particular Omega transmission. The Dynell receiver can also be synchronized manually by advancing or retarding the receiver reference to a known received Omega signal using the reference and signal lamps.

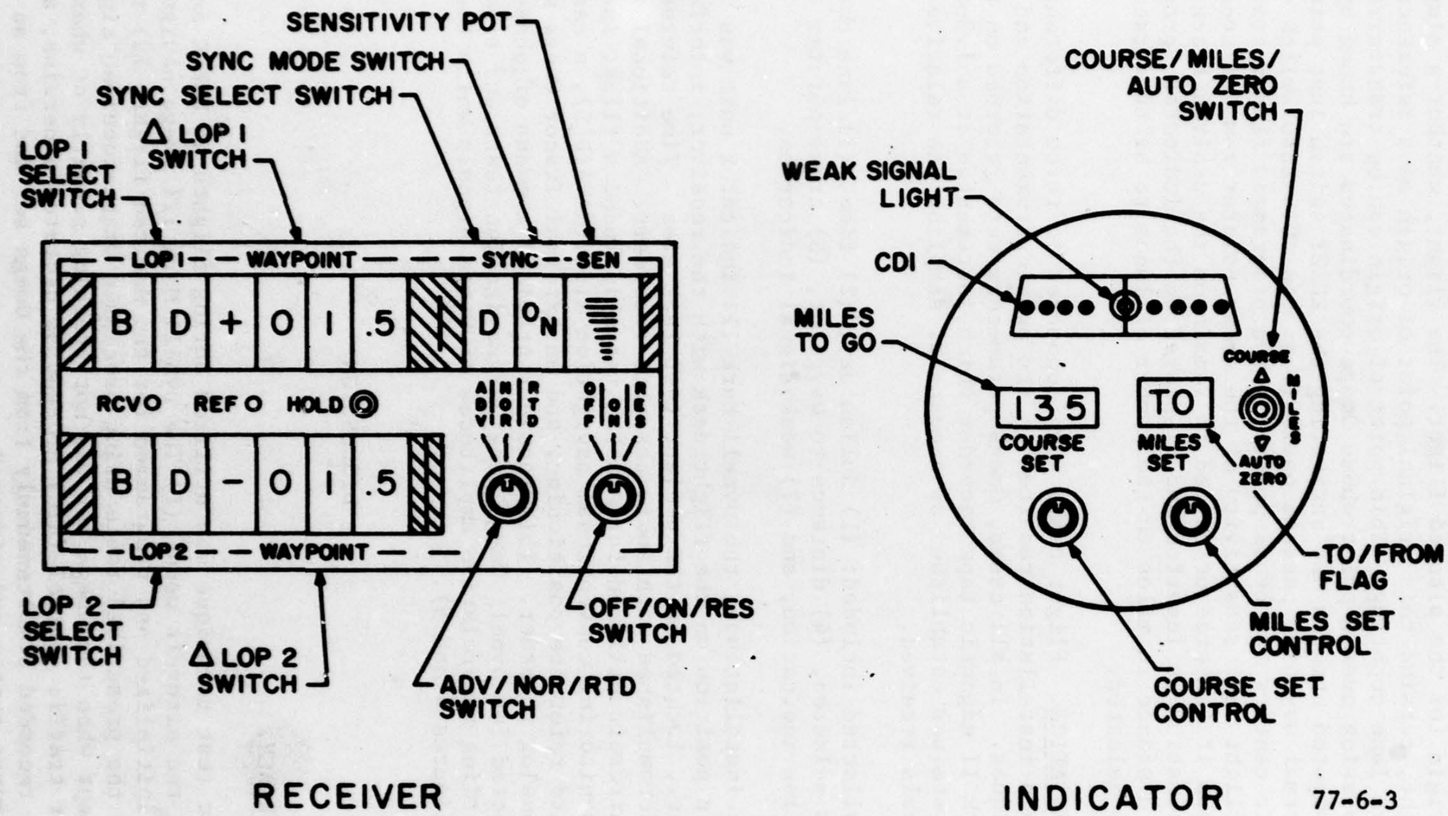

FIGURE 3. MARK III OMEGA CONTROLS AND INDICATORS

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The RESET switch zeros the lane accumulator within the receiver and establishes a point of origin for the planned flight. The flight, whether a single or multileg flight, retains this original point of origin as a reference for all internal Omega lane counting. This point of origin can be transferred in flight when passing over a point whose Omega coordinates are known by inserting the proper computed numbers and activating the RESET switch just prior to performing normal waypoint passage operations. An AUTO-ZERO switch on the indicator unit centers the cross-pointer for a programmed flight track. For a given flight leg, sensitivity of the cross-pointer remains constant, and the pilot keeps it centered or nulled to remain on the desired track. Trip distance information is inserted and displayed on the indicator, properly scaling trip distance in miles to the number of lanes to be traversed for the pair of LOP's selected.

TEST INSTRUMENTATION. Flight tests were conducted in three different FAA aircraft. Each installation resulted in its own instrumentation and operational techniques. In all cases, Omega parameters were recorded on the Incredata Mark II magnetic tape recorder which incremented at a 1.3-second rate. This rate was established as a means of sampling the relative amplitude of Omega signals received.

Other data collected included: (1) Julian day, (2) time, (3) lane counts for station pairs selected, (4) distance to waypoint, (5) cross-pointer deviation, (6) TO/FROM flag indication, and (7) weak-signal indication.

For all three installations, the Dynell Mark III indicator unit was installed at the pilot's position on the flight deck with the receiver, interfacing, recorders, etc., located in the project test rack area. Time referenced flight logging was accomplished with audio cassette recorders. Additional instrumentation in the aircraft utilized for Alaskan tests included a flight inspection console for monitoring conventional navigation aids (NAVAID'S), a camera for filming onboard reference positioning, and an external Tracor Omega monitoring system with analog recorder. This recorder provided a means of phase monitoring stations selected for Dynell Omega receiver navigation tests and a secondary means of recording the relative amplitudes of Omega signals while tests were in progress (figures 4 and 5).

DISCUSSION

METHOD OF APPROACH.

The same basic test technique was utilized during flights at NAFEC and Alaska, regardless of the aircraft used: (1) The Dynell Mark III Omega navigation receiver was initialized and programmed for the desired flight, (2) the aircraft flew the prescribed route using processed Omega-received signals for guidance, except when the Omega set was not tracking properly or when flight safety and air traffic control (ATC) procedures dictated otherwise, and (3) data were recorded simultaneously from the Omega set and from an acceptable position-reference system and compared.

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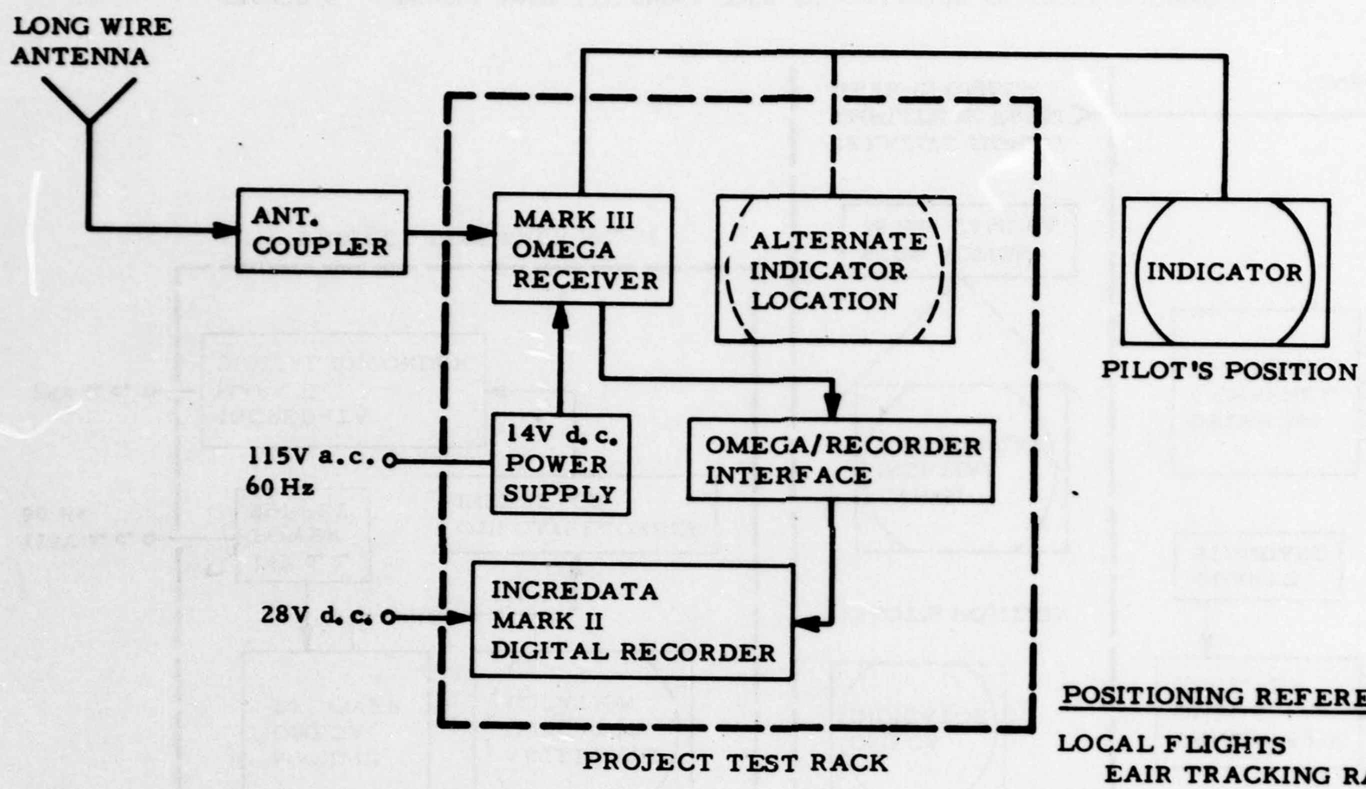

POSITIONING REFERENCES

LOCAL FLIGHTS
EAIR TRACKING RADAR

LONG RANGE FLIGHTS
FLIGHT INSPECTION
CONSOLE WITH DUAL
VOR/DME CAPABILITY

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FIGURE 4. AEROCOMMANDER/DC-6 OMEGA TEST INSTALLATION

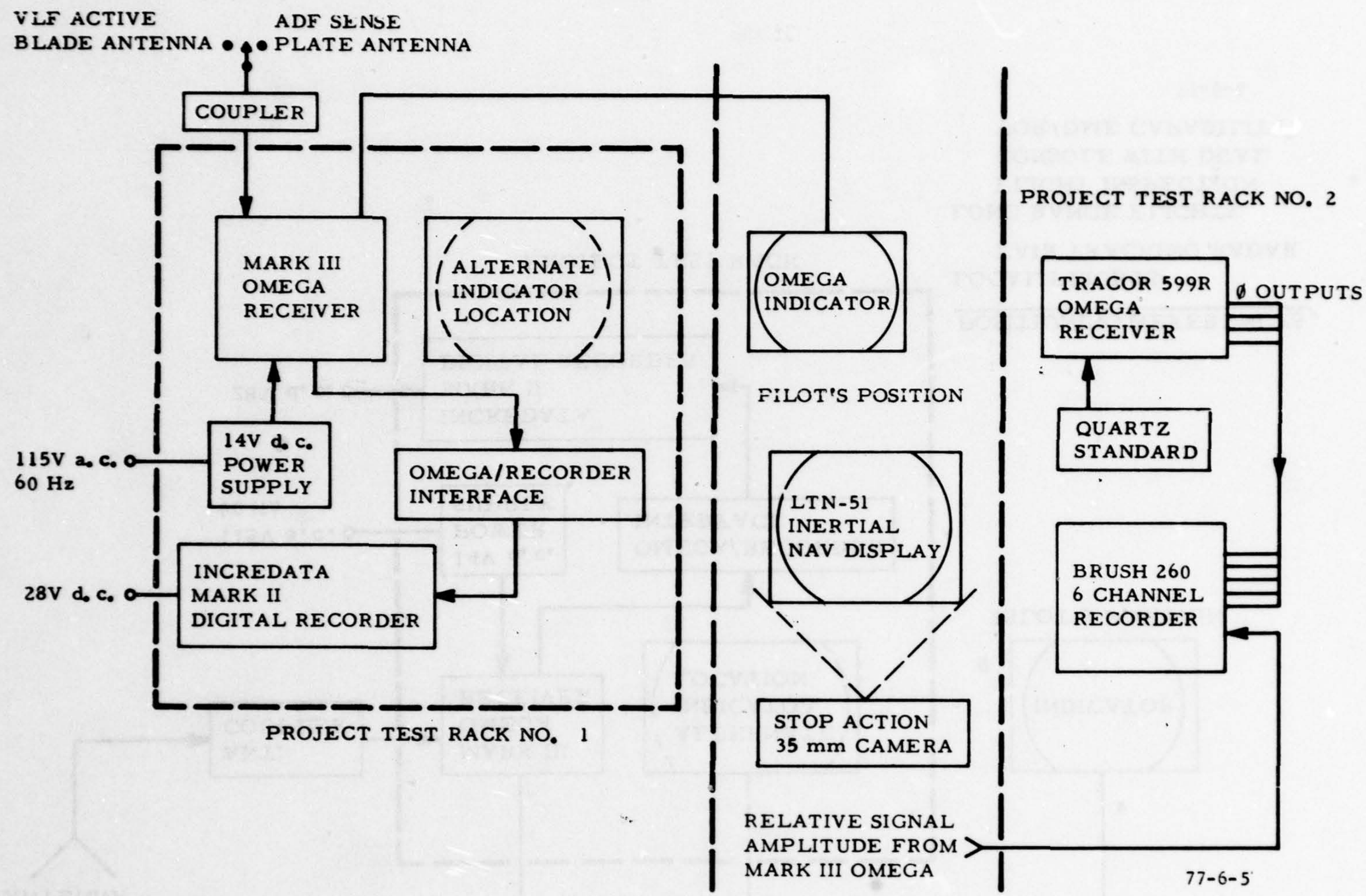

FIGURE 5. DYNELL MARK III OMEGA TEST INSTALLATION ON CONVAIR CV880

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NAFEC FLIGHTS.

Initial flights in the vicinity of NAFEC were accomplished in an FAA Aero-Commander, AC680, twin-engine aircraft. This aircraft was equipped with a standard, top-mounted long-wire antenna deemed suitable for Omega signal reception. Single-leg tests at altitudes ranging up to 14,000 feet mean sea level (m.s.l.) with speeds of approximately 160 knots were flown using the Extended Area Instrumentation Radar (EAIR) tracking facility located at NAFEC as an external positioning reference. Southerly routes extending to 112 nmi from NAFEC were selected for ease of repeatability. This phase of testing was conducted during quiescent daytime and diurnal transition periods.

The Dynell Mark III Omega receiver and related instrumention was then installed on an FAA Douglas DC6B aircraft for testing in Alaska. This aircraft had been selected because of its operating range, relatively low-operating speed (240 knots), and the fact that it was equipped with long-wire antenna usable for Omega reception. Two multiwaypoint data collection flights were conducted at NAFEC with this configuration as an operational check prior to departing for Alaska. Unfortunately, the Alaskan flight tests planned for January 1975 had to be postponed shortly after arriving at Anchorage because of a maintenance shutdown of the Omega station in Hawaii. At the time these local flight tests and the Alaskan attempt were made, only four Omega stations were operating: Norway, Trinidad, North Dakota, and Hawaii. Hawaii was not fully operational, but was necessary in order to conduct Omega tests in Alaska.

ALASKAN FLIGHT TESTS.

Revised Omega test flights in Alaska were accomplished in May 1975, using an FAA Convair CV880 jet aircraft (figure 6), the only aircraft available at the time for long-range flight testing. This aircraft was deemed suitable, because it could be flown at speeds as low as 300 knots. A very positive addition to flight planning and data collection was the fact that the CV880 had a Litton LTN-51 inertial navigation system (INS) onboard for use as a position reference during the entire test series. Ramp inspections and one very brief local test flight were conducted prior to departing for Alaska. These tests were limited because the aircraft was required for higher priority projects. The tests demonstrated successful operation of the test installation at speeds of 300 knots or less during normal aircraft maneuvers. Antenna investigation indicated that two of the antennas on the aircraft were usable for Omega signal reception during the visual flight rules (VFR) flight conditions encountered. These were an automatic direction finder (ADF) plate sensing unit and an active, very low frequency (VLF) band blade, which had been installed for a previous project. It was not possible to assess the performance of these antennas in the extreme flying environment which exists in Alaska prior to departure.

All flights originated and terminated at Anchorage except for flights 5 and 5A. They were flown on standard air routes at published minimum enroute altitudes (MEA's) and at groundspeeds of approximately 300 knots. All flights were accomplished during daylight hours, commencing at approximately 10:00 a.m. local time. Anchorage time in May was Greenwich mean time (GMT) minus 9 hours. The six test flight routes are depicted in figure 7.

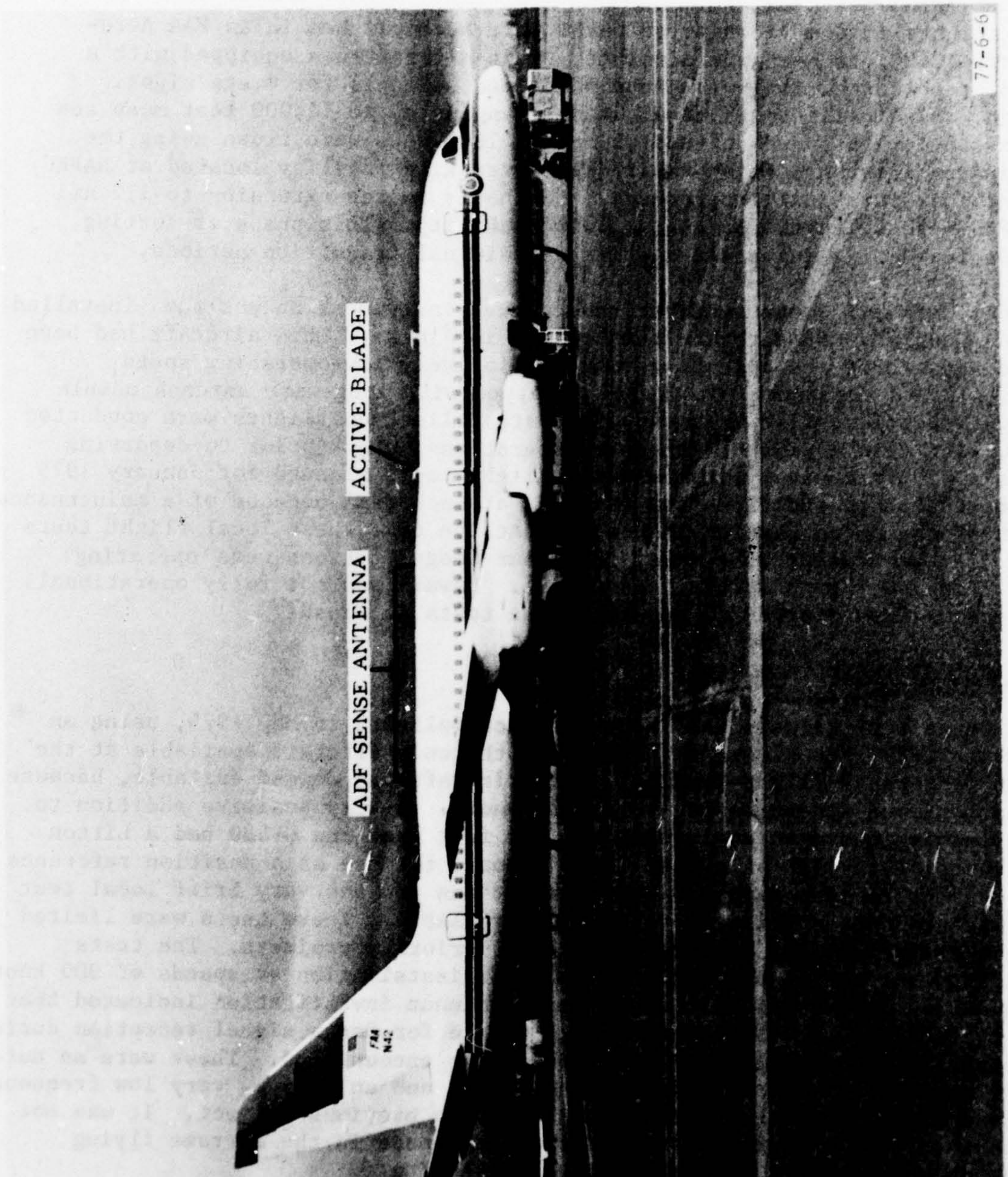

FIGURE 6. CONVAIR CV880

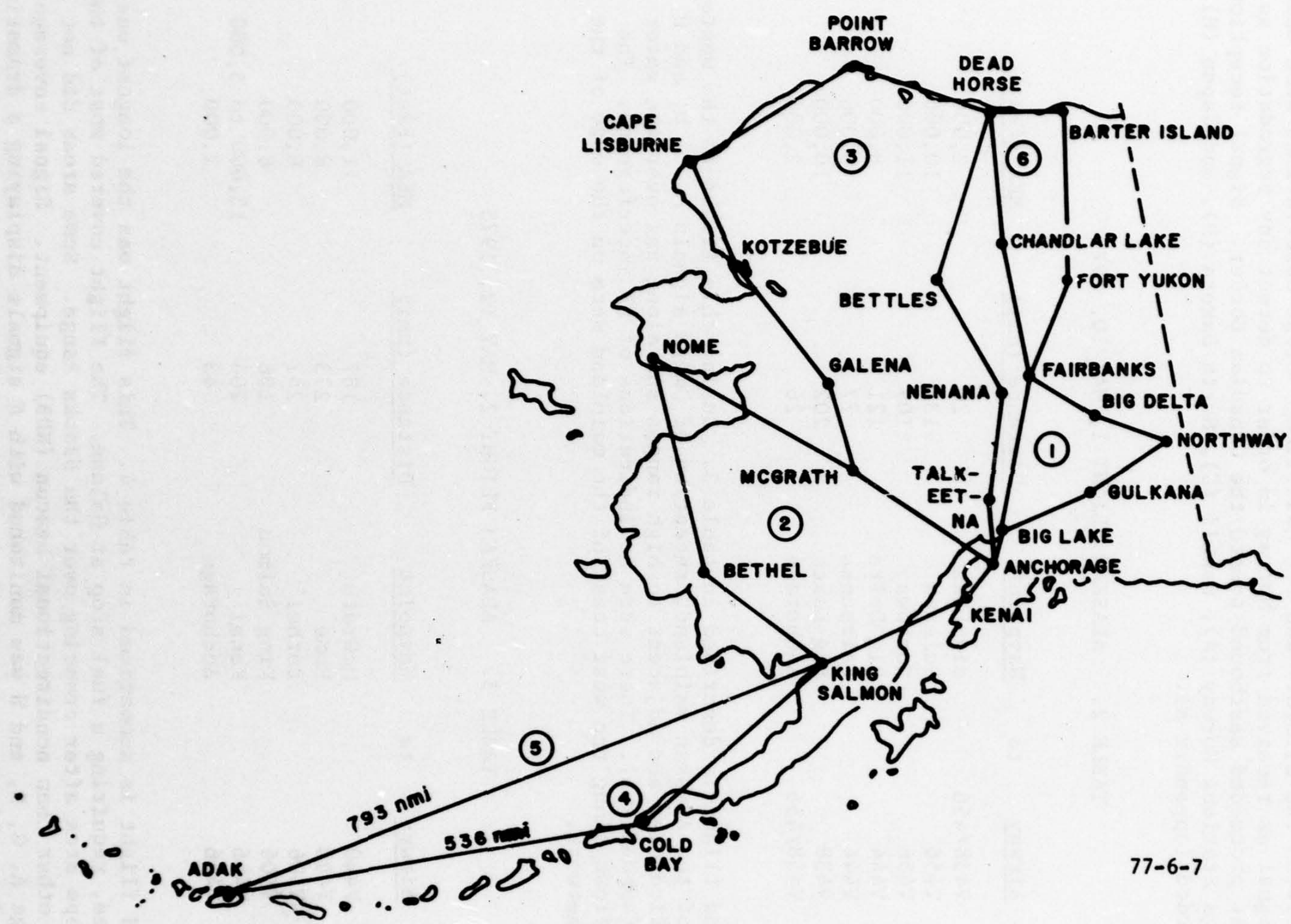

FIGURE 7. ALASKAN FLIGHT ROUTES

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The initial relatively short flight (table 2) in the southeast central portion of the state demonstrated operation and signal reception over various types of terrain. The legs from Northway to Fairbanks were flown in a valley with high ranges between the aircraft and the coastline. Close observations were made of the signal as received from Norway in order to detect any degradation as the flight proceeded eastbound toward the Canadian Border. Signal reception from Omega Stations Norway (A), Hawaii (C), North Dakota (D), and Japan (H) was recorded (appendix A).

TABLE 2. ALASKAN FLIGHT 1, MAY 10, 1975

Segment	Airway	to	Waypoint	Distance (nmi)	MEA (feet)
1	V438/456		Big Lake	26	2,000
2	V456		Gulkana	133	10,000
3	V456		Northway	109	11,000
4	V444		Big Delta	121	8,000
5	V444		Fairbanks	77	5,000
6	V438		Big Lake	202	10,000
7	V438/456		Anchorage	26	2,000

The second flight is described in table 3. During this flight to the western portion of the Alaskan mainland, reception of Omega signals A, C, D, and H was verified over and adjacent to high ranges and along and over the water segment (appendix A). There were no indications of RF interference. The airways flown along the west coast of the mainland were on the edge of the VOR/DME network.

TABLE 3. ALASKAN FLIGHT 2, MAY 12, 1975

Segment	Airway	to	Waypoint	Distance (nmi)	MEA (Feet)
1	V440		McGrath	187	11,000
2	V440		Nome	273	8,000
3	V506		Bethel	242	8,000
4	V506		King Salmon	198	8,000
5	V456		Kenai	204	13,000 to 5,000
6	V456		Anchorage	43	2,000

The third flight is summarized in table 4. This flight was the longest one of the series, requiring a fuel stop at Galena. The flight covered most of the North Slope area after crossing over the Brooks Range. Some areas did not have NAVAID's other than nondirectional beacon (NDB) equipment. Signal coverage from Omega A, C, D, and H was monitored with A signals displaying a dramatic increase in quality as we progressed northbound (appendix A).

TABLE 4. ALASKAN FLIGHT 3, MAY 12, 1975

Segment	Airway	to	Waypoint	Distance (nmi)	MEA (Feet)
1	V436		Talkeetna	69	3,000
2	V436		Nenana	141	10,000
3	V504		Bettles	152	7,000
4	V504		Dead Horse	211	10,000 to 7,000
5	A15		Pt. Barrow	177	6,000 Actual
			Cape Lisburne	240	6,000 Actual
			Kotzebue	143	6,000 Actual
6	V498		Galena (fuel)	192	8,000

A brief equipment and operational check flight was performed as shown in table 5. This flight also served to demonstrate Omega navigation for the Director, Alaskan Region, and members of his staff. Operation of low-cost Omega and all related systems onboard were demonstrated and explained. Multi-waypoint operations and functions of the controls were examined.

TABLE 5. OMEGA EQUIPMENT AND OPERATIONAL CHECK FLIGHT, MAY 14, 1975

Segment	Airway	to	Waypoint	Distance (nmi)	MEA (Feet)
1	V438/456		Big Lake	26	2,000
2	V438		Fairbanks	202	10,000
3	V438		Big Lake	202	10,000
4	V438/456		Anchorage	26	2,000

The fourth flight is outlined in table 6. This test provided information on Omega signal coverage in the Aleutian Chain between Cold Bay and Adak. A 536-nmi course was flown over water originating at Cold Bay and terminating at Adak. The Tactical Air Navigation Aid (TACAN) at Adak was inoperative during the test period. Omega signals A, C, D, and H were monitored (appendix A).

TABLE 6. ALASKAN FLIGHT 4, MAY 15, 1975

Segment	Airway	to	Waypoint	Distance (nmi)	MEA (Feet)
1	V456		Kenai	43	2,000
2	V456		King Salmon	204	13,000
3	V456		Cold Bay	287	14,000
			Adak	536	14,000

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Data from the fifth flight is given in table 7. This flight was planned to provide a single leg that was 793-nmi long for navigation testing over the Bering Sea enroute to Anchorage. The flight was aborted when a problem developed in the LTN-51 reference. A return to origin was initiated in the Omega test system. Proper operation of Omega during the inbound leg was confirmed by Adak Radar at a distance of 50 nmi. The LTN-51 problem was resolved after landing and the test flight was reinitiated.

TABLE 7. ALASKAN FLIGHT 5, MAY 16, 1975

Segment	Airway	to	Waypoint	Distance (nmi)	MEA (Feet)
1			Approx. 300 nmi NE of Adak		13,000 actual
2			Return to Adak		13,000 actual

After the aborted attempt, this flight, the fifth of the planned series (table 8), demonstrated operation of a low-cost Omega on a single-leg that was 793-nmi flight over water. Omega signals A, C, D, and H were monitored and/or utilized for Dynell navigation (appendix A).

TABLE 8. ALASKAN FLIGHT 5A, MAY 16, 1975

Segment	Airway	to	Waypoint	Distance (nmi)	MEA (Feet)
1			King Salmon	793	13,000
2	V456		Kenai	204	13,000
3	V436/456		Anchorage	43	2,000

Table 9 lists data from the sixth flight. This flight was aborted approximately 100 nmi north of Anchorage because of an unscheduled outage of Omega station at Hawaii. Rather than lose data legs enroute, while waiting for the station to resume transmission, the test was terminated. Signals from Hawaii were received again prior to landing at Anchorage.

TABLE 9. ALASKAN FLIGHT 6, MAY 18, 1975

Segment	Airway	to	Waypoint	Distance (nmi)	MEA (Feet)
1	V438/456		Big Lake	26	2,000
2	V438		A point approx. 100 nmi north of Anchorage		

After the aborted flight, test 6A, (table 10) was conducted as the last of the planned series conducted in Alaska. The course was designed to traverse the remainder of the North Slope east of Prudhoe Bay and the airway roughly paralleling the Canadian border between Barter Island and Fairbanks. In addition, this route provided a repeat leg over V438 between Fairbanks and Anchorage for data comparison.

TABLE 10. ALASKAN FLIGHT 6A, MAY 19, 1975

Segment	Airway	to	Waypoint	Distance (nmi)	MEA (Feet)
1	V438/456		Big Lake	26	2,000
2	V438		Fairbanks	202	10,000
3	V347		Chandalar Lake	164	11,000
4	A15		Dead Horse	163	10,000
5			Barter Island	98	10,000 actual
6	B26		Fort Yukon	217	12,000
7	V438		Fairbanks	127	8,000
8	V438		Big Lake	202	10,000
9	V438/456		Anchorage	26	2,000

TEST RESULTS

NAFEC FLIGHTS (RADAR POSITION REFERENCE).

Table 11 lists the results of six flights in the Aerocommander at NAFEC. In addition to these flights, several demonstrations were flown. The results presented in the table are considered typical Mark III Omega performance during the Aerocommander flight test phase. The results indicate that with good signal reception and reasonable geometry of Omega station pairs selected, end point accuracies of 2 nmi or less with enroute positioning well within ±4 nmi (2 sigma) may be obtained during quiescent propagation conditions. The flight test conducted during the evening diurnal period on October 23, 1974, verified that compensation, manual or automatic, is necessary in order to fly from one point to another with reasonable accuracy during diurnal transition periods. Scatter plots and distribution graphs of cross-track and along-track error are located in appendices B and C.

The column of figures, titled "LAST SAMPLE" listed in tables 11 through 19, represent the results of processing the last usable data recorded just prior to overflying a waypoint. These figures may be considered a measure of end-point accuracy.

Severe noise conditions and loss of Omega reception occurred during all flights to Westminster, Maryland, in the western half of the flight leg. The reason for this has not been determined, but signal reception was good arriving and departing at the NAFEC end of the flight legs.

TABLE 11. OMEGA POSITION ERROR, SINGLE WAYPOINT FLIGHTS, AEROCOMMANDER

Date	Route	DIS (nmi)	Sample Size	Parameters	Mean (nmi)	St. Dev. (nmi)	2 St. Dev. (nmi)	Last Sample (nmi)
9/27/74	NAFEC	94	1561	Crosstrack	+ 1.3574	+ 1.9926	+ 3.9851	- 0.3538
	Snowhill		1561	Along Track	- 3.1173	+ 3.1173	+ 6.2346	- 0.7266
10/23/74	NAFEC	94	1529	Crosstrack	+ 1.1622	+ 1.1622	+ 2.3243	- 0.3266
	Snowhill		1529	Along Track	+ 1.5975	+ 1.8227	+ 3.6455	+ 1.7409
	Snowhill	94	1721	Crosstrack	- 3.2860	+ 2.8187	+ 5.6375	- 8.4168*
	NAFEC		1721	Along Track	+ 3.5152	+ 4.3927	+ 8.7854	- 5.4702
	NAFEC	94	1370	Crosstrack	- 0.0401	+ 1.0964	+ 2.1928	+ 2.4205
	Snowhill		1370	Along Track	- 0.2081	+ 1.0705	+ 2.1410	- 1.0276
	Snowhill	94	1615	Crosstrack	+ 0.9709	+ 0.7723	+ 1.5446	- 0.6605
	NAFEC		1613	Along Track	+ 1.2795	+ 1.4419	+ 2.8838	- 0.8391
	NAFEC	112	2028	Crosstrack	- 1.0101	+ 0.9903	+ 1.9806	- 2.4535
10/24/74	Westminster		2028	Along Track	+ 0.0798	+ 2.0832	+ 4.1664	- 2.1675
	Westmin-ster	112	1653	Crosstrack	- 2.5656	+ 0.8588	+ 1.7175	- 1.8339
	NAFEC		1653	Along Track	+12.1685	+ 4.7936	+ 9.5873	+12.2733
	NAFEC	112	1512	Crosstrack	- 0.6577	+ 1.7733	+ 3.5466	- 2.2462
	Westminster		1512	Along Track	- 3.9466	+ 3.3265	+ 6.6531	+10.2807
	Westmin-ster	112	1139	Crosstrack	- 1.4617	+ 0.4066	+ 0.8131	- 1.9058
	NAFEC		1139	Along Track	+17.7418	+ 2.4603	+ 4.9207	+11.4873
10/25/74	NAFEC	112	1995	Crosstrack	- 0.6559	+ 1.0598	+ 2.1197	- 1.2055
	Westminster		1859	Along Track	+ 0.1637	+ 1.1476	+ 2.2953	- 2.0544
	Westmin-ster	112	1267	Crosstrack	No Tracking on OMEGA-weak signals			
	NAFEC		1267	Along Track				
11/22/74	NAFEC	112	1969	Crosstrack	+ 2.3336	+ 1.7670	+ 3.5340	+ 3.8504
	Westminster		1924	Along Track	+ 3.5656	+ 2.0506	+ 4.1012	+ 8.2115
	Westmin-ster	112			No tracking on OMEGA - weak signals			
	NAFEC							
12/11/74	NAFEC	79	1469	Crosstrack	+ 1.3622	+ 0.8371	+ 1.6742	+ 0.2988
	Salisbury		1468	Along Track	- 0.9667	+ 2.0597	+ 4.1194	+ 5.2734
	Salisbury	79			No tracking on OMEGA - weak signals			
	NAFEC							

NOTE: Crosstrack "-" means left, "+" means right of track
Along Track "-" means lagging or behind, "+" means leading or ahead
*Evening diurnal phase shift period

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It is possible that, since the test aircraft was not dedicated solely to this project, removal and reinstallation of instrumentation between flight tests could have caused some problems. However, a multiwaypoint flight with a Dynell representative aboard was flown successfully in the Long Island Sound area, verifying the installation at that time.

Tables 12 and 13 illustrate the results obtained during the two test flights conducted in a Douglas DC6B aircraft. These results were consistent and indicated that multiwaypoint flights with endpoint accuracy of 2 nmi or less and enroute positioning well within ± 4 nmi (2 sigma) could be expected during quiescent periods. These flights were conducted at altitudes ranging up to 17,000 feet. Scatter plots and error distribution graphs of these data are given in appendices B and C.

ALASKAN FLIGHTS (INERTIAL POSITION REFERENCE).

Transcontinental flights to and from Alaska were flown for other commitments; therefore, Mark III navigation tests were not performed enroute. The flight from NAFEC to Anchorage and return served only to observe Omega signal reception (figure 8) and, on the westbound route, to ascertain that the most usable antenna onboard the CV880 aircraft was an active VLF blade, installed for a previous project. This antenna was employed during all Alaskan probes. Tables 14 through 19 list the results of these probes, and scatter plots and error distribution curves for these data are given in appendices B and C.

It became apparent early in the Alaska flight test series that although the aircraft was flying at reduced speeds, high noise levels and impaired signal reception were occurring everytime the aircraft encountered heavy clouds and snow showers. The aircraft was equipped with static dischargers in good condition. The signal degradation experienced was apparently caused by a number of factors, including aircraft velocity and the density of the impurities which were impinging on the aircraft. The flight legs which were affected by these conditions are noted in the tables. Flights 2, 3, and 4 lost complete data collection legs because of this problem. The plots and graphs in the appendix illustrate this factor. Other possible causes for error included some inaccurate waypoint marks, and the possibility that published latitudes and longitudes, particularly in the fringe areas, may be inaccurate. The CV880, because of fuel requirements and starting characteristics, had only a few airports available for landing. This resulted in subjecting the Mark III Omega receiver to rather severe testing, with round trips of up to 1,600 nmi involving long distances between waypoints. Despite these negative factors, examination of the flight legs conducted in VFR conditions, with a reasonable starting mark, indicated an enroute standard deviation factor of less than 3 nmi and endpoint accuracies of 4 nmi or less. Flight 5A, enroute from Adak to King Salmon, suffered an unexplainable loss of signals in clear air, followed by a project power outage not related to signal loss. A successful Omega restart was accomplished a short time later using an upcoming inertial navigation waypoint as the new origin. The coordinates for this new origin were obtained from an Omega chart.

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TABLE 12. OMEGA POSITION ERROR, MULTIWAYPOINT FLIGHT, DECEMBER 18, 1974, FLIGHT TEST 7, DC6B

Route	Distance (nmi)	Sample Size	Parameters	Mean (nmi)	St. Dev. (nmi)	2 St. Dev. (nmi)	Last Sample (nmi)
NAFEC	24	875	Crosstrack	+ 0.5824	+ 0.7578	+ 1.5155	+ 1.5055
Sea Isle		149	Along Track	+ 0.5776	+ 0.7104	+ 1.4208	- 0.7267
Sea Isle	118	1259	Crosstrack	- 0.2982	+ 0.5494	+ 1.0988	- 0.4868
SHAD		708	Along Track	- 0.9710	+ 0.9696	+ 1.9392	- 0.7266
SHAD	118	1998	Crosstrack	- 0.2357	+ 1.3126	+ 2.6252	- 1.5321
Sea Isle		818	Along Track	- 0.5212	+ 0.6824	+ 1.3649	- 0.4451
Sea Isle	98	508	Crosstrack	- 0.6686	+ 1.4486	+ 2.8973	+ 1.6308
Norfolk (Partial)		345	Along Track	- 0.7408	+ 1.2081	+ 2.4161	+ 2.2656
Norfolk (Partial)	112	785	Crosstrack	+ 1.9175	+ 0.3688	+ 0.7376	+ 1.9743
NAFEC		453	Along Track	+ 0.5621	+ 0.8504	+ 1.7009	- 1.5698
Total	480	4820	Crosstrack	+ 0.1002	+ 1.3294	+ 2.6588	+ 1.9743
		2473	Along Track	+ 0.1400	+ 1.1328	+ 2.2657	- 1.5698

TABLE 13. OMEGA POSITION ERROR, MULTIWAYPOINT FLIGHT, DECEMBER 19, 1974, FLIGHT TEST 8, DC6B

Route	Distance (nmi)	Sample Size	Parameters	Mean (nmi)	St. Dev. (nmi)	2 St. Dev. (nmi)	Last Sample (nmi)
NAFEC	36		Crosstrack	No Data - Aircraft Diverted			
Woodstown			Along Track				
Woodstown	81	1187	Crosstrack	+ 0.4627	+ 2.2305	+ 4.4610	+ 0.3527
Ravine		465	Along Track	+ 0.1913	+ 1.0689	+ 2.1377	- 1.5128
Ravine	19	267	Crosstrack	+ 1.7181	+ 1.6050	+ 3.2100	- 0.1831
Selinsgrove		200	Along Track	- 0.2208	+ 1.0968	+ 2.1937	- 0.9382
Selinsgrove	19	194	Crosstrack	- 1.2580	+ 1.2338	+ 2.4677	- 0.0804
Ravine		108	Along Track	+ 2.2007	+ 0.8474	+ 1.70	- 1.1101
Ravine	81	793	Crosstrack	+ 1.4058	+ 1.1073	+ 2.2145	- 0.8674
Woodstown		129	Along Track	+ 1.0102	+ 0.6524	+ 1.3048	+ 1.8679
Woodstown	36	295	Crosstrack	+ 0.6900	+ 0.3549	+ 0.7099	+ 1.2596
NAFEC		170	Along Track	+ 0.5946	+ 0.6387	+ 1.2774	+ 0.4067
Total	272	2736	Crosstrack	+ 0.2288	+ 1.8181	+ 3.6361	+ 1.2596
		1072	Along Track	+ 0.4774	+ 1.2648	+ 2.5296	+ 0.4067

NOTE: Crosstrack "-" means left,"+" means right of track
Along Track "-" means lagging or behind, "+"means leading or ahead

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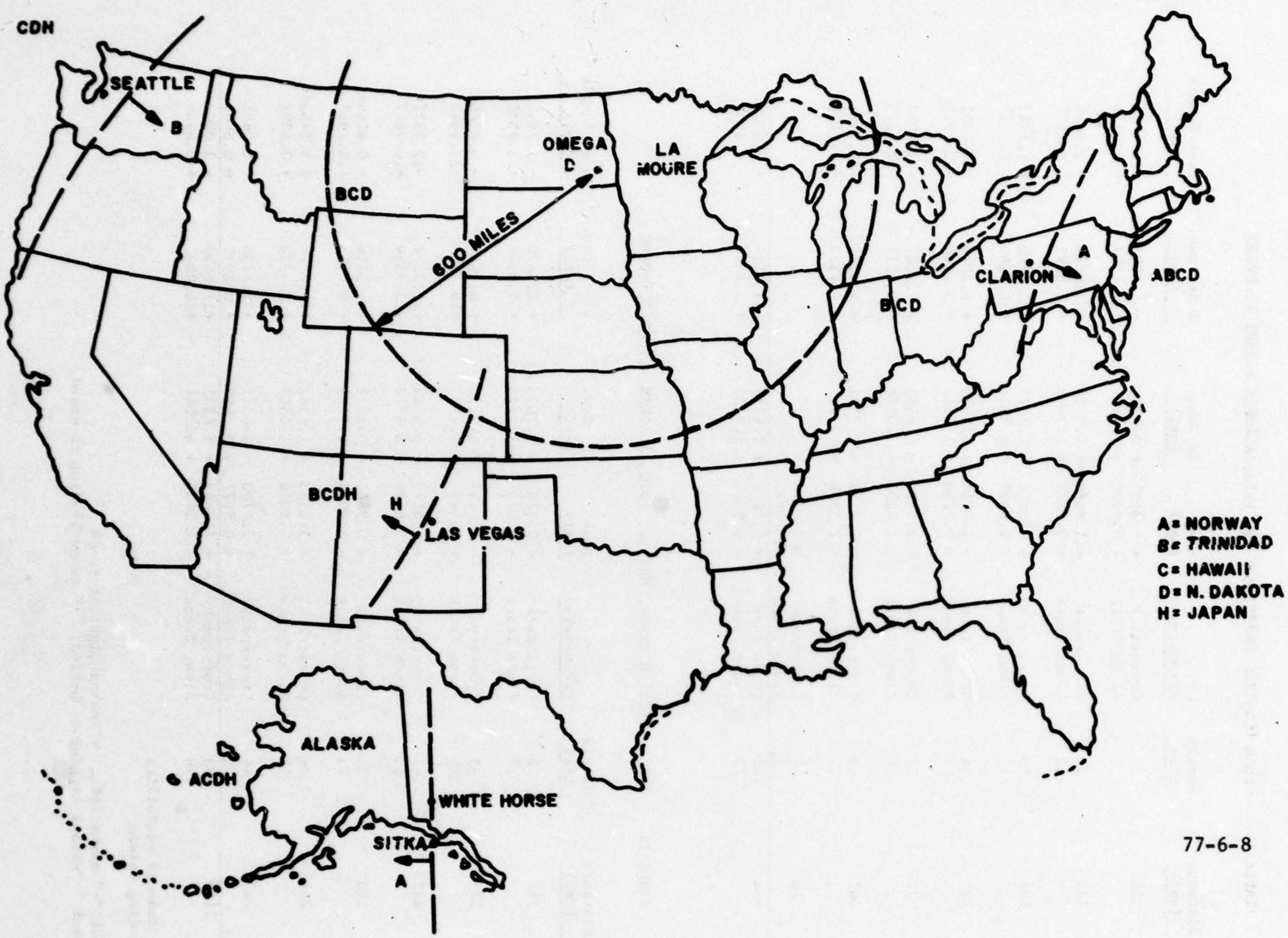

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FIGURE 8. OMEGA RECEPTION LIMITS, MAY 1975

TABLE 14. OMEGA POSITION ERROR, MAY 10, 1975, ALASKAN FLIGHT 1, CV880

Route	Distance (nmi)	Sample Size	Parameters	Mean (nmi)	St. Dev. (nmi)	2 St. Dev. (nmi)	Last Sample (nmi)
Anchorage	26	4	Crosstrack	+ 1.8535	+ 0.9393	+ 1.8786	+ 0.8786
Big Lake		2	Along Track	- 0.9996	+ 0.0791	+ 0.1583	- 1.0555
Big Lake	133	26	Crosstrack	+ 1.8616	+ 1.3114	+ 2.6228	+ 2.0248
Gulkana		15	Along Track	+ 0.9126	+ 1.3496	+ 2.6991	- 0.2037
Gulkana	109	19	Crosstrack	+ 0.3056	+ 1.1375	+ 2.2750	+ 1.1793
Northway		17	Along Track	+ 0.6622	+ 0.8834	+ 1.7669	- 0.2177
Northway	121	16	Crosstrack	- 1.0014	+ 3.2024	+ 6.4048	+ 2.8951
Delta Junction		8	Along Track	+ 0.2290	+ 1.8782	+ 3.7564	+ 2.1965
Delta Junction	77	13	Crosstrack	+ 2.1494	+ 0.9583	+ 1.9167	+ 1.7983
Fairbanks		8	Along Track	- 1.4003	+ 1.0686	+ 2.1372	- 1.4213
Fairbanks	202	40	Crosstrack	- 2.3139	+ 2.3132	+ 4.6264	+ 0.3126
Big Lake		22	Along Track	+ 2.3380	+0.7161	+ 1.4322	+ 1.9123
Big Lake	26	1	Crosstrack	No Data			
Anchorage		1	Along Track	No Data			
Total	694	118	Crosstrack	+ 0.1627	+ 2.6717	+ 5.3434	+ 2.5581
		72	Along Track	+ 0.9426	+ 1.5735	+ 3.1470	- 4.4057

TABLE 15. OMEGA POSITION ERROR, MAY 12, 1975, ALASKAN FLIGHT 2, CV880

Route	Distance (nmi)	Sample Size	Parameters	Mean (nmi)	St. Dev. (nmi)	2 St. Dev. (nmi)	Last Sample (nmi)
Anchorage	187	8	Crosstrack	+ 0.3707	+ 1.2835	+ 2.5670	+ 1.7941
McGrath		5	Along Track	- 1.070	+ 1.9273	+ 3.8547	+ 3.8938
McGrath	273	45	Crosstrack	- 6.0194	+ 3.0830	+ 6.1660	- 0.4286*
Nome		24	Along Track	+ 5.3467	+ 9.2105	+18.4209	+22.9447
Nome	242	41	Crosstrack	+ 6.6177	+ 5.6789	+11.3577	+12.8571*
Bethel		25	Along Track	- 9.6729	+ 6.3770	+12.7539	+16.9617
Bethel	198	34	Crosstrack	+ 0.9641	+ 0.6099	+ 1.2198	+ 0.4664*
King Salmon		23	Along Track	- 3.2044	+ 4.5465	+ 9.0929	+10.1917
King Salmon	204	36	Crosstrack	+ 3.8583	+ 1.6387	+ 3.2775	+ 5.2463**
Kenai		19	Along Track	+ 2.9046	+ 1.0368	+ 2/-838	+ 0.6992
Kenai	43	44	Crosstrack	+ 2.4703	+ 1.0577	+ 2.1154	+ 3.0802
Anchorage		2	Along Track	+ 0.9971	+ 0.1445	+ 0.2891	+ 0.8949
Total	1147	168	Crosstrack	+ 1.0659	+ 5.8205	+11.6409	+ 3.0802
		98	Along Track	- 1.2634	+ 8.3044	+16.089	+ 0.8949

* Snow showers, reduced visibility

** Poor mark at King Salmon

NOTE: Crosstrack "-" means left, "+" means right of track
Along Track "-" means lagging or behind, "+" means leading or ahead

TABLE 16. OMEGA POSITION ERROR, MAY 13, 1975, ALASKAN FLIGHT 3, CV880

Route	Distance (nmi)	Sample Size	Parameters	Mean (nmi)	St. Dev. (nmi)	2 St. Dev. (nmi)	Last Sample (nmi)
Anchorage	69	10	Crosstrack	+ 0.1524	+ 1.4434	+ 2.8868	- 1.4403
Talkeetna		5	Along Track	+ 4.0625	+ 1.2671	+ 2.5343	+ 4.8413
Talkeetna	141	23	Crosstrack	- 2.6573	+ 0.8078	+ 1.6156	- 3.8916
Nenana		15	Along Track	+ 2.8875	+ 0.6732	+ 1.3464	+ 3.3633
Nenana	152	27	Crosstrack	- 1.7614	+ 3.4480	+ 6.8959	- 2.4025
Bettles		15	Along Track	+ 4.1444	+ 1.8008	+ 3.6016	+ 6.0292
Bettles	211	32	Crosstrack	- 6.5297	+ 0.8178	+ 1.6357	- 6.0125
Dead Horse		20	Along Track	+ 5.6789	+ 1.0445	+ 2.0890	+ 4.4149
Dead Horse	177	21	Crosstrack	- 7.1359	+ 1.5771	+ 3.1543	- 8.1253
Point Barrow		12	Along Track	+ 3.4914	+ 1.5031	+ 3.0062	+ 2.4723
Point Barrow	240	35	Crosstrack	- 7.6275	+ 2.2390	+ 4.4780	- 5.8065
Cape Lisburne		20	Along Track	- 5.7124	+ 1.8489	+ 3.6979	- 1.5134
Cape Lisburne		143	Crosstrack	-18.0816	+ 7.0892	+14.1784	-14.6147*
Kotzebue			Along Track	-11.6672	+ 3.9666	+ 7.9333	- 3.0369**
Kotzebue	192	28	Crosstrack	- 9.9862	+ 1.0554	+ 2.1107	+ 7.5610**
Galena		19	Along Track	- 4.2317	+ 5.8776	+11.7551	-10.0062
Galena	112	19	Crosstrack	+ 1.6736	+ 1.2493	+ 2.4987	+ 3.4654
McGrath		9	Along Track	- 1.4986	+ 2.8634	+ 5.7267	+ 0.6627
McGrath	187	34	Crosstrack	+ 1.0780	+ 3.2751	+ 6.5502	+ 2.2783
Anchorage		19	Along Track	+ 1.3553	+ 1.1143	+ 2.2287	+ 2.4369
Total	1624	259	Crosstrack	- 5.7395	+ 6.6270	+13.2540	+ 2.2783
		149	Along Track	+ 0.5683	+ 6.0387	+12.0774	+ 2.4369

* Poor mark at Cape Lisburne
** Snow, reduced visibility

TABLE 17. OMEGA POSITION ERROR, MAY 15, 1975, ALASKAN FLIGHT 4, CV880

Route	Distance (nmi)	Sample Size	Parameters	Mean (nmi)	St. Dev. (nmi)	2 St. Dev. (nmi)	Last Sample (nmi)
Anchorage	43	5	Crosstrack	- 1.3237	+ 1.8532	+ 3.7064	- 0.3960
Kenai		3	Along Track	+ 2.3433	+ 3.6769	+ 7.3538	+ 6.5827
Kenai	204	-	Cross Track	Poor Reception - No Data		*	
King Salmon		-	Along Track			**	
King Salmon	287	40	Crosstrack	- 2.5130	+ 3.9656	+ 7.9313	- 4.9849**
Cold Bay		22	Along Track	- 3.3396	+ 8.2205	+16.4409	+17.3019***
Cold Bay	536	63	Crosstrack	- 2.3542	+ 2.0636	+ 4.1272	- 3.7289***
Adak		31	Along Track	-14.4266	+ 3.3485	- 6.6970	-10.5568
Total	1070	114	Crosstrack	- 2.5005	+ 2.8915	+ 5.7829	- 3.7289***
		61	Along Track	- 2.7042	+19.6155	+39.2310	-10.5568

* Groundspeed in excess of 300 Knots
** Snow showers, reduced visibility
*** Performed RESET, Transferring Origin to King Salmon and Cold Bay

NOTE: Crosstrack "-" mean left, "+" means right of track
Along Track "-" means lagging or behind, "+" means leading or ahead

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TABLE 18. OMEGA POSITION ERROR, MAY 16, 1975, ALASKAN FLIGHT 5A, CV880

Route	Distance (nmi)	Sample Size	Parameters	Mean (nmi)	St. Dev. (nmi)	2 St. Dev. (nmi)	Last Sample (nmi)
Adak	793	40	Crosstrack	- 3.8225	+ 0.6678	+ 1.3357	- 3.4406
King Salmon		24	Along Track	+ 7.4954	+ 3.9028	+ 7.8056	- 1.1031
King Salmon	204	34	Crosstrack	- 1.6128	+ 1.4772	+ 2.9544	+ 1.3470
Kenai		23	Along Track	+ 3.9457	+ 0.5409	+ 1.0818	+ 3.6867
Kenai	43	-	Crosstrack	No Data - Improper Program			
Anchorage		-	Along Track				
Total	1040	117	Crosstrack	- 3.4170	+ 1.6511	+ 3.3022	+ 1.3470
		74	Along Track	+ 9.0223	+ 7.5654	+15.1308	+ 3.6867

TABLE 19. OMEGA POSITION ERROR, MAY 19, 1975, ALASKAN FLIGHT 6A, CV880

Route	Distance (nmi)	Sample Size	Parameters	Mean (nmi)	St. Dev. (nmi)	2 St. Dev. (nmi)	Last Sample (nmi)
Anchorage	26	3	Crosstrack	- 1.7921	+ 0.3807	+ 0.7615	- 1.3573
Big Lake		2	Along Track	- 1.2038	+ 0.5614	+ 1.229	- 0.8068
Big Lake	202	25	Crosstrack	- 3.8518	+ 2.6861	+ 5.3722	- 2.4162
Fairbanks		16	Along Track	+ 0.1664	+ 1.4920	+ 2.9840	- 0.1173
Fairbanks	164	30	Crosstrack	- 0.0402	+ 2.0876	+ 4.1753	- 2.9540
Chandelar Lake		23	Along Track	+ 5.9841	+ 0.6838	+ 1.3675	+ 5.2722
Chandelar Lake	163	21	Crosstrack	+ 0.8980	+ 1.9729	+ 3.9458	- 3.1470
Dead Horse		10	Along Track	+ 4.8771	+ 3.6342	+ 7.2684	- 0.5459
Dead Horse	98	19	Crosstrack	+ 0.9588	+ 0.5573	+ 1.1146	+ 0.5575
Barter Bland		10	Along Track	- 0.2010	+ 1.8332	+ 3.6665	- 2.5652
Barter Bland	217	34	Crosstrack	- 2.6255	+ 2.2918	+ 4.5836	- 0.2692
Fort Yukon		21	Along Track	+ 1.4136	+ 0.6686	+ 1.3371	+ 1.0820
Fort Yukon	127	25	Crosstrack	+ 2.6763	+ 2.0049	+ 4.0048	+ 0.4185
Fairbanks		13	Along Track	+ 6.3159	+ 1.9682	+ 3.9364	+ 9.9012
Fairbanks	202	29	Crosstrack	- 0.9438	+ 1.9924	+ 3.9849	+ 2.1137
Big Lake		15	Along Track	+ 5.5798	+ 2.1274	+ 4.2548	+ 8.3080
Big Lake	26	-	Crosstrack	No Data			
Anchorage		-	Along Track				
Total	1225	186	Crosstrack	- 0.6211	+ 2.8915	+ 5.7830	+ 2.1137
		110	Along Track	- 3.4558	+ 3.1637	+ 6.3274	+ 8.3080

NOTE: Crosstrack "-" means left, "+" means right of track
Along Track "-" means lagging or behind, "+" means leading or ahead

30

CONCLUSIONS

The Dynell Mark III navigation receiver performed satisfactorily as a feasibility test system. This equipment was flight tested for two purposes: (1) to test the concept of employing low-cost Omega avionics for navigation in civil aircraft, and (2) to probe the Omega propagation environment which exists both within designated airways and in remote areas where VOR/DME airway routes have not yet been established. The flight tests performed should not be construed as certification trials because criteria and performance specifications pertaining to the use of Omega as a primary air navigation system have not yet been established and approved. A major requirement of any air navigation system under consideration for use as a supplement/replacement for VOR/DME is that it be compatible to the existing airways systems and procedures, and its navigational accuracy be equal to or greater than the specifications presently in effect. It is for this reason that the terms 2 sigma and ± 4 miles are mentioned in the text. The following statements relate to the Omega navigation receiver and to the signal environment observed in Alaska.

1. The course deviation indicator appeared to be too sensitive in comparison to a conventional enroute deviation indicator.

2. The lack of internal phase compensation and the need for manual arithmetic computations prior to flight would definitely require phase compensation lists at flight planning locations, and probably involve an indepth knowledge on the part of the pilot for application.

3. Automatic syncronization to received Omega format would have reduced the equipment initialization workload.

4. Conceptually, single-frequency Omega receivers would be suitable for navigational use by a large segment of the civil aviation fleet in the lower performance category.

5. During the Alaskan flight test period Omega transmissions from Norway, North Dakota, Hawaii, and Japan were received on all routes except when precipitation static interfered with reception. The majority of the problems arising during all phases of the Alaskan test were attributed to the type of aircraft utilized and the lack of a suitable antenna.

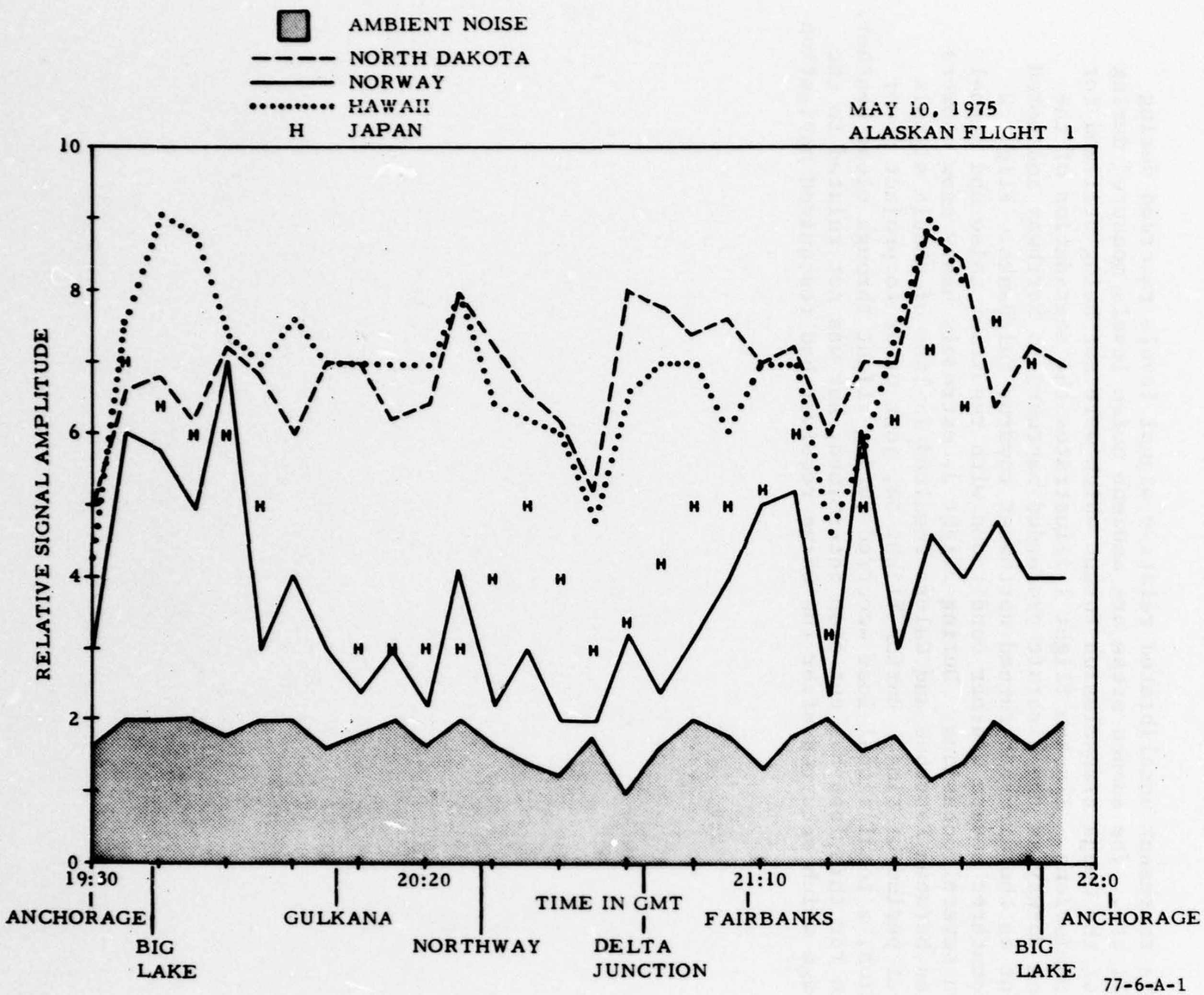
6. The Omega station in Japan had not been placed in full operational status, but it was apparent that when commissioned, this station too would be usable throughout Alaska.

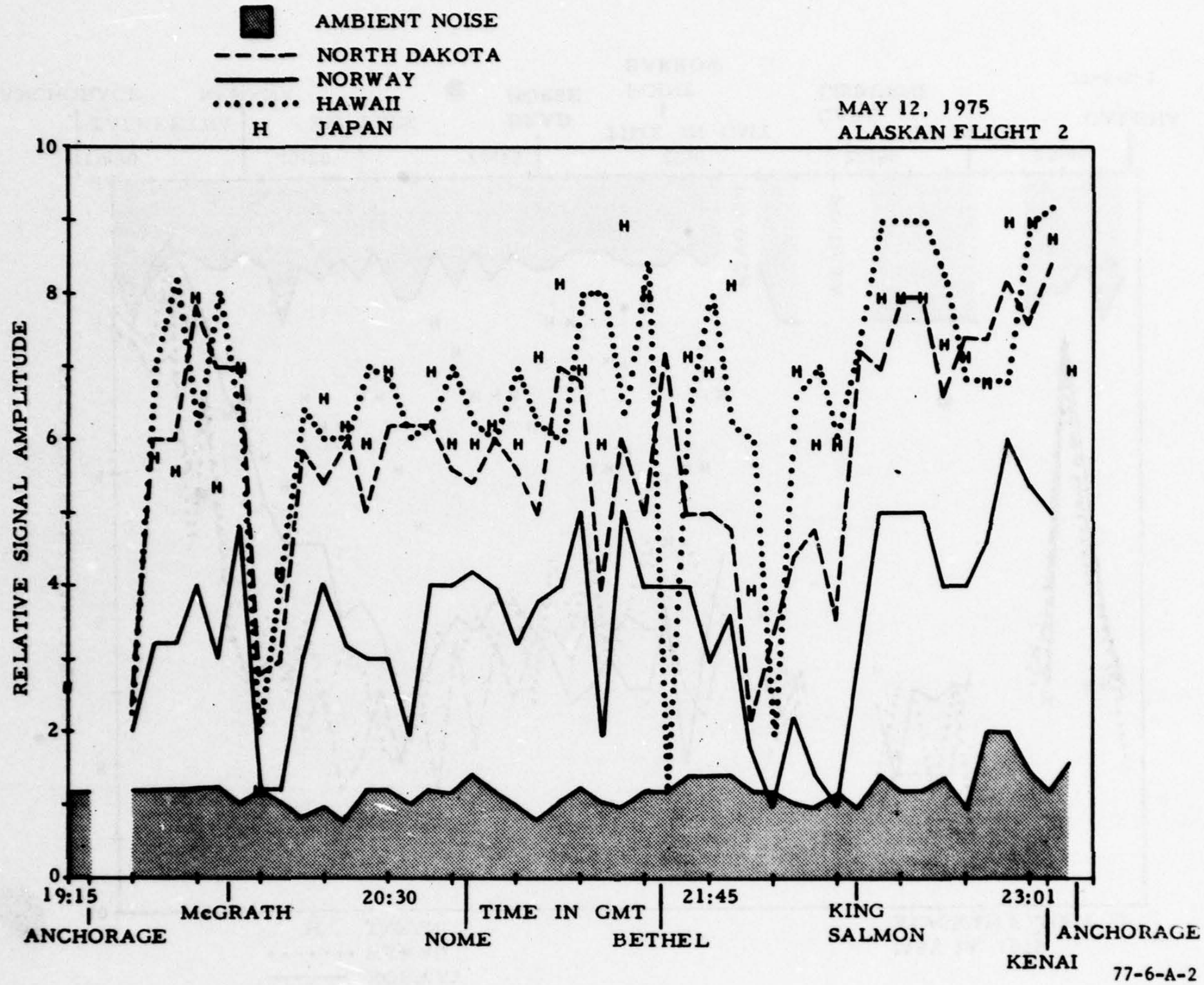
7. This series of Alaskan flight tests was conducted at minimum enroute altitudes at speeds of approximately 300 knots. A subsequent series of probes was flown at jet altitudes with an experimental automatic Omega system. The data collected indicates that the use of Omega for air navigation in Alaska shows promise, but final conclusions cannot be drawn without additional investigation involving low-level test flights and ground monitoring facilities.

APPENDIX A

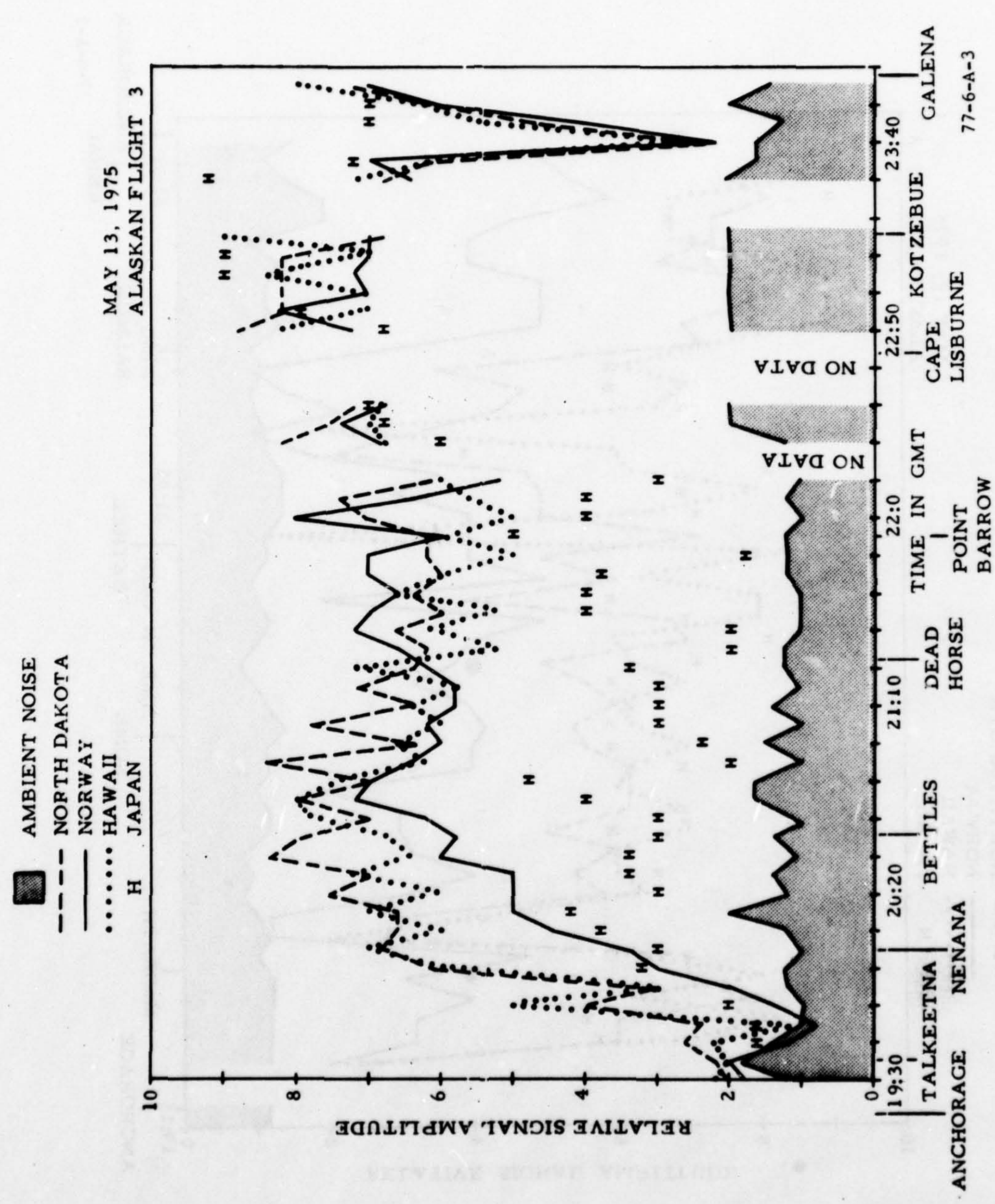
RELATIVE AMPLITUDE OF OMEGA TRANSMISSIONS RECEIVED IN ALASKA

These plots represent uncalibrated relative signal levels recorded during Alaskan flights. The shaded areas are ambient noise levels measured during segments of the Omega transmission format which were not being utilized for Omega transmissions. Alaskan flight 1 illustrates the degradation of the signal from Norway as the aircraft proceeded eastward to Northway and noted improvement as the aircraft turned northwest towards Fairbanks. Flight 2 and 4 encountered severe weather conditions with resultant noise and signal dropout on several occasions. During flight 3, extremely heavy snow showers encountered between Kotzebue and Galena resulted in loss of usable signals for a brief period of time. During flight 5A, just prior to project power interruption, a total signal loss occurred during flight through clear weather. The reason for this loss has not been determined, but was not related to the power outage which occurred after the Omega receiver had reacquired navigation signals.


AMBIENT NOISE
NORTH DAKOTA
NORWAY
HAWAII
H JAPAN
MAY 10, 1975
ALASKAN FLIGHT 1
RELATIVE SIGNAL AMPLITUDE
0
2
4
6
8
10
19:30
20:20
21:10
22:0
TIME IN GMT
ANCHORAGE
BIG LAKE
GULKANA
NORTHWAY
DELTA JUNCTION
FAIRBANKS
BIG LAKE
ANCHORAGE
77-6-A-1

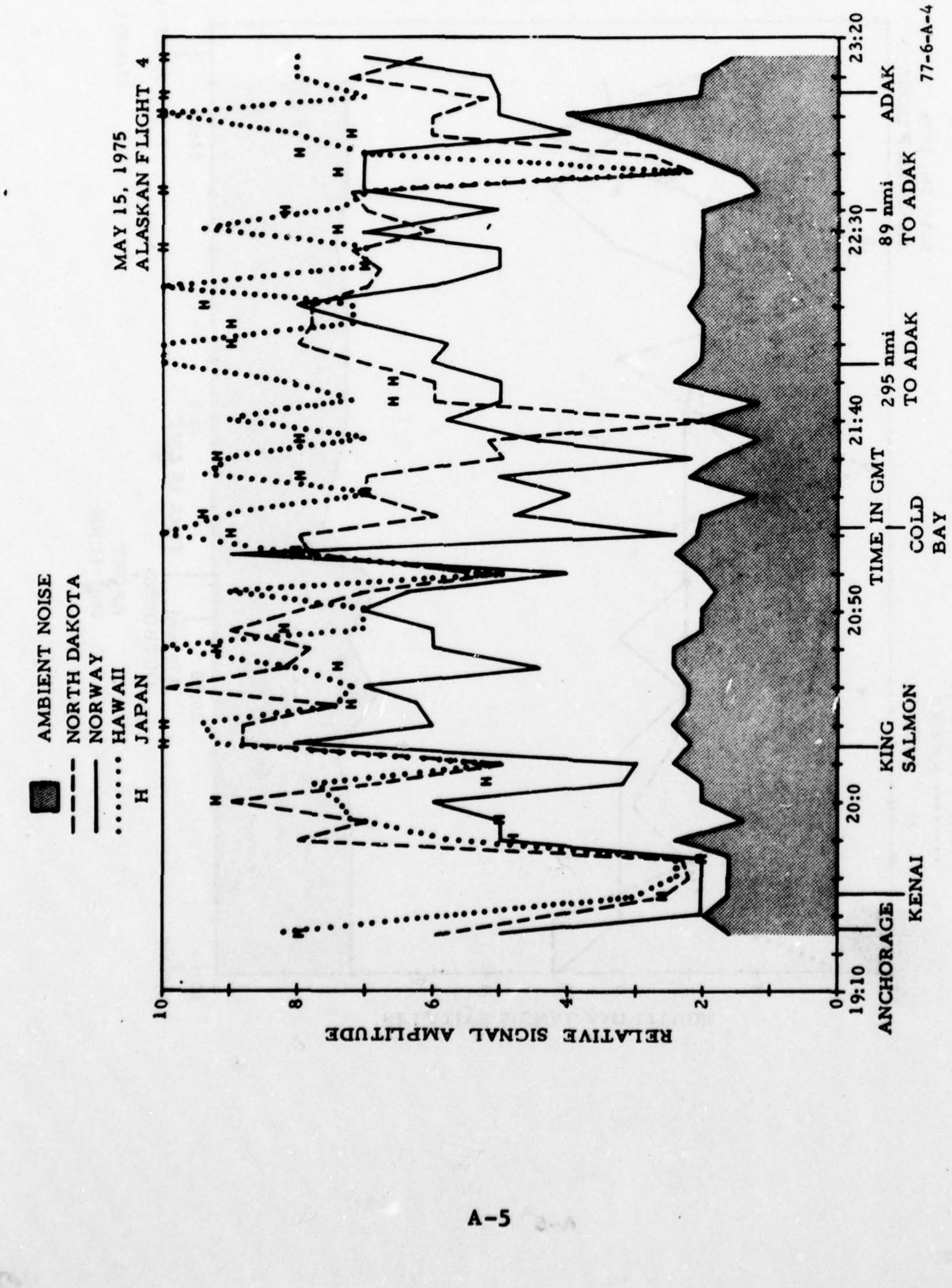

AMBIENT NOISE
NORTH DAKOTA
NORWAY
HAWAII
H JAPAN
MAY 12, 1975
ALASKAN FLIGHT 2
RELATIVE SIGNAL AMPLITUDE
0
2
4
6
8
10
19:15
20:30
21:45
23:01
TIME IN GMT
ANCHORAGE
McGRATH
NOME
BETHEL
KING SALMON
KENAI
ANCHORAGE
77-6-A-2

34


MAY 13, 1975
ALASKAN FLIGHT 3
AMBIENT NOISE
NORTH DAKOTA
NORWAY
HAWAII
H JAPAN
RELATIVE SIGNAL AMPLITUDE
0
2
4
6
8
10
19:30
20:20
21:10
22:0
22:50
23:40
TIME IN GMT
NO DATA
NO DATA
ANCHORAGE
TALKEETNA
NENANA
BETTLES
DEAD HORSE
POINT BARROW
CAPE LISBURNE
KOTZEBUE
GALENA

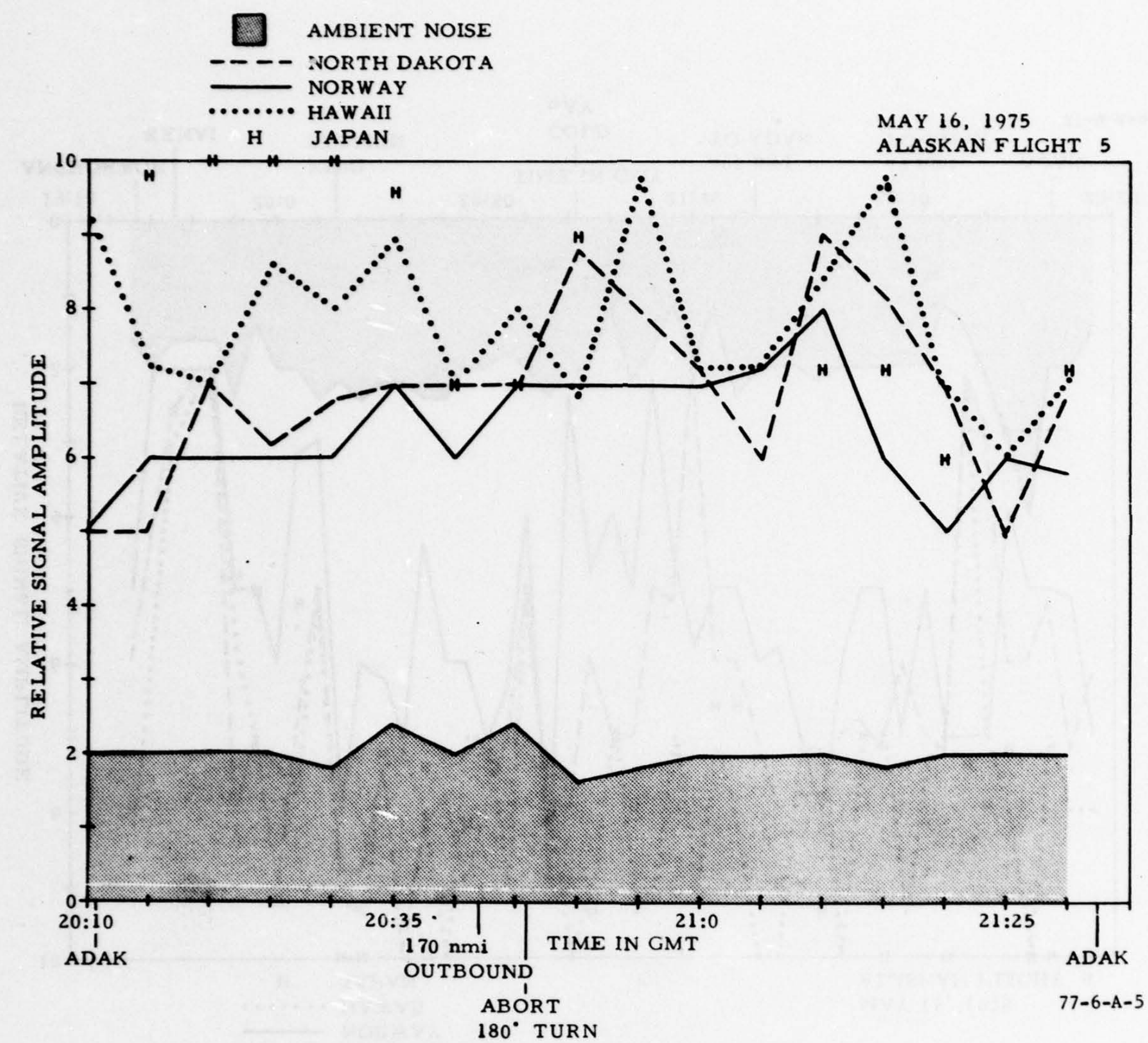
77-6-A-3

35

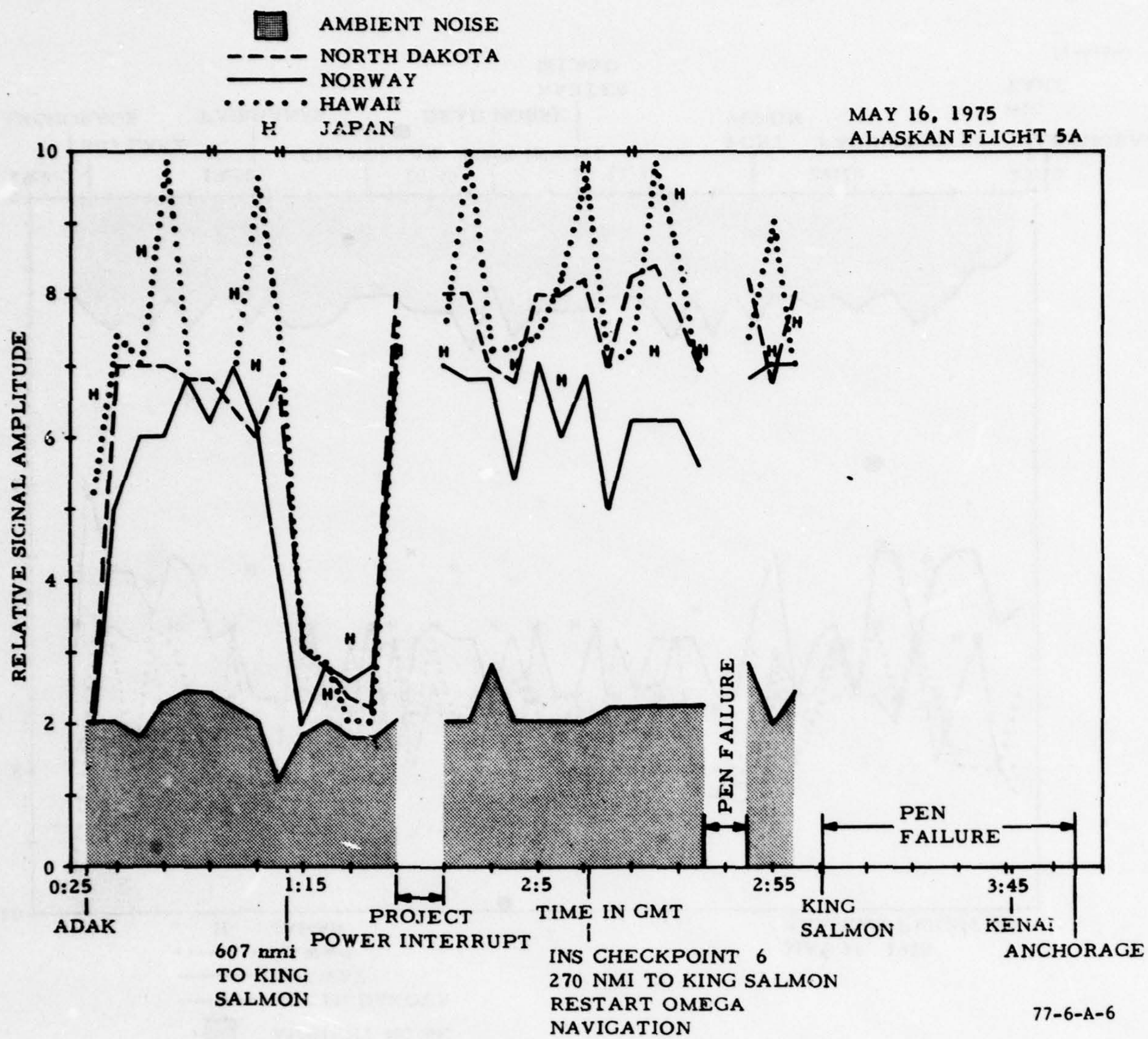


AMBIENT NOISE
NORTH DAKOTA
NORWAY
HAWAII
H JAPAN
MAY 15, 1975
ALASKAN FLIGHT 4
RELATIVE SIGNAL AMPLITUDE
0
2
4
6
8
10
19:10
20:0
20:50
21:40
22:30
23:20
TIME IN GMT
ANCHORAGE
KENAI
KING SALMON
COLD BAY
295 nmi TO ADAK
89 nmi TO ADAK
ADAK
77-6-A-4

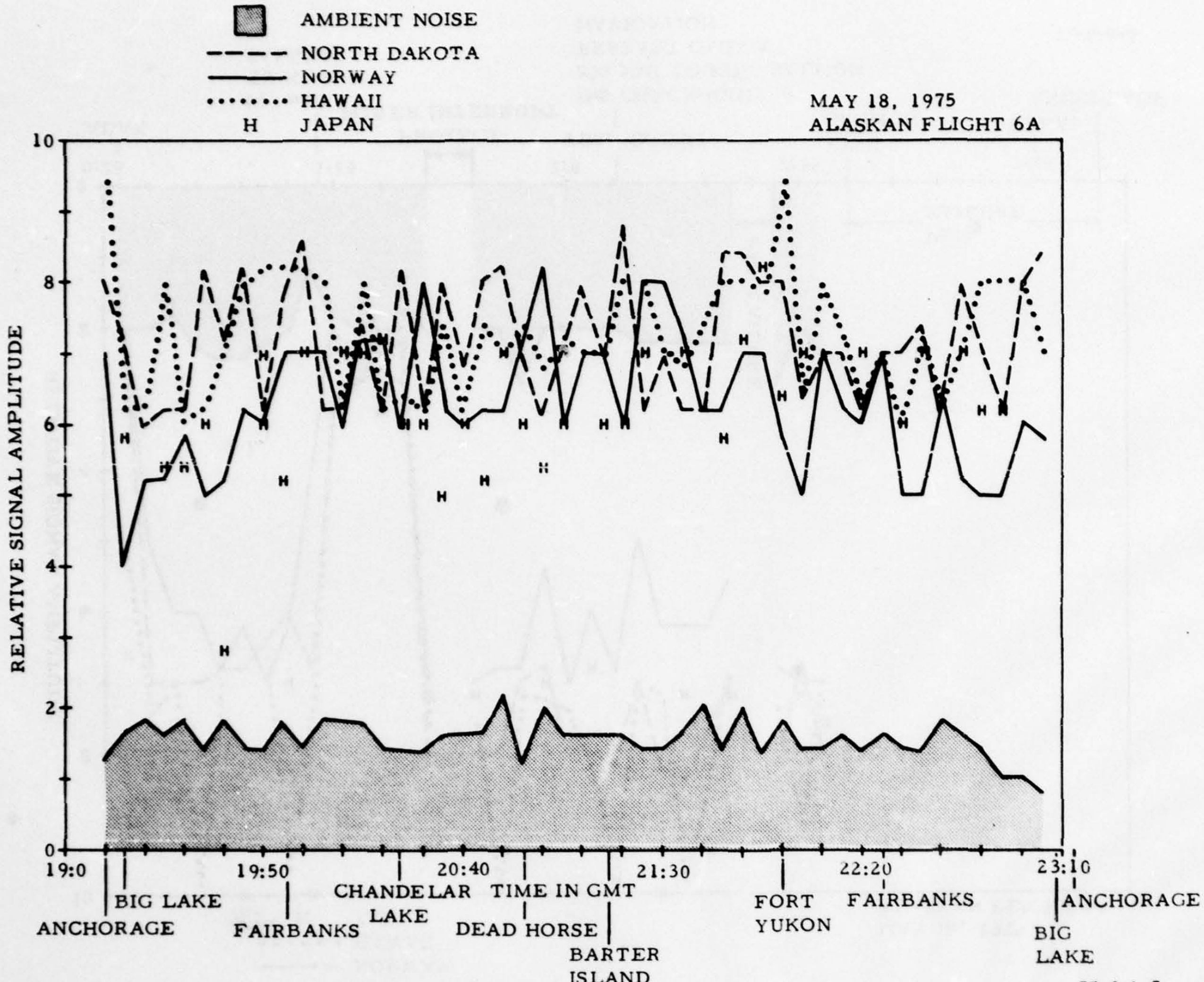
36



AMBIENT NOISE
NORTH DAKOTA
NORWAY
HAWAII
H JAPAN
MAY 16, 1975
ALASKAN FLIGHT 5
RELATIVE SIGNAL AMPLITUDE
0
2
4
6
8
10
20:10
ADAK
20:35
170 nmi
OUTBOUND
ABORT
180° TURN
TIME IN GMT
21:0
21:25
ADAK
77-6-A-5



AMBIENT NOISE
NORTH DAKOTA
NORWAY
HAWAII
H JAPAN
MAY 16, 1975
ALASKAN FLIGHT 5A
RELATIVE SIGNAL AMPLITUDE
10
8
6
4
2
0
0:25
1:15
2:5
2:55
3:45
ADAK
607 nmi
TO KING
SALMON
PROJECT
POWER INTERRUPT
TIME IN GMT
INS CHECKPOINT 6
270 NMI TO KING SALMON
RESTART OMEGA
NAVIGATION
PEN FAILURE
KING
SALMON
PEN
FAILURE
KENAI
ANCHORAGE
77-6-A-6



AMBIENT NOISE
NORTH DAKOTA
NORWAY
HAWAII
H JAPAN
MAY 18, 1975
ALASKAN FLIGHT 6A
RELATIVE SIGNAL AMPLITUDE
10
8
6
4
2
0
19:0
19:50
20:40
21:30
22:20
23:10
TIME IN GMT
ANCHORAGE
BIG LAKE
FAIRBANKS
CHANDELAR LAKE
DEAD HORSE
BARTER ISLAND
FORT YUKON
FAIRBANKS
BIG LAKE
ANCHORAGE

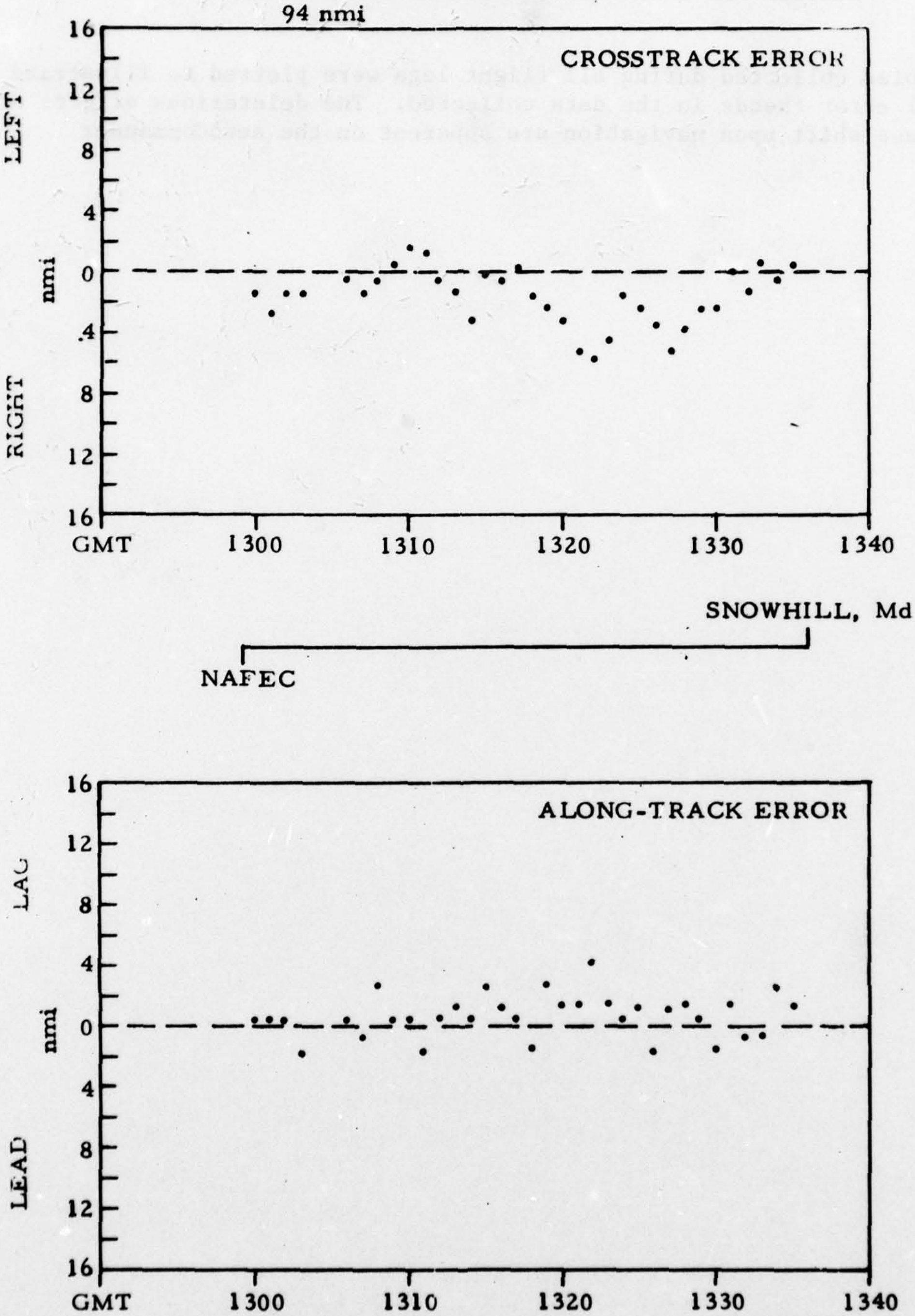
77-6-A-7

APPENDIX B

SCATTER PLOTS OF ALONG-TRACK AND CROSS-TRACK ERROR

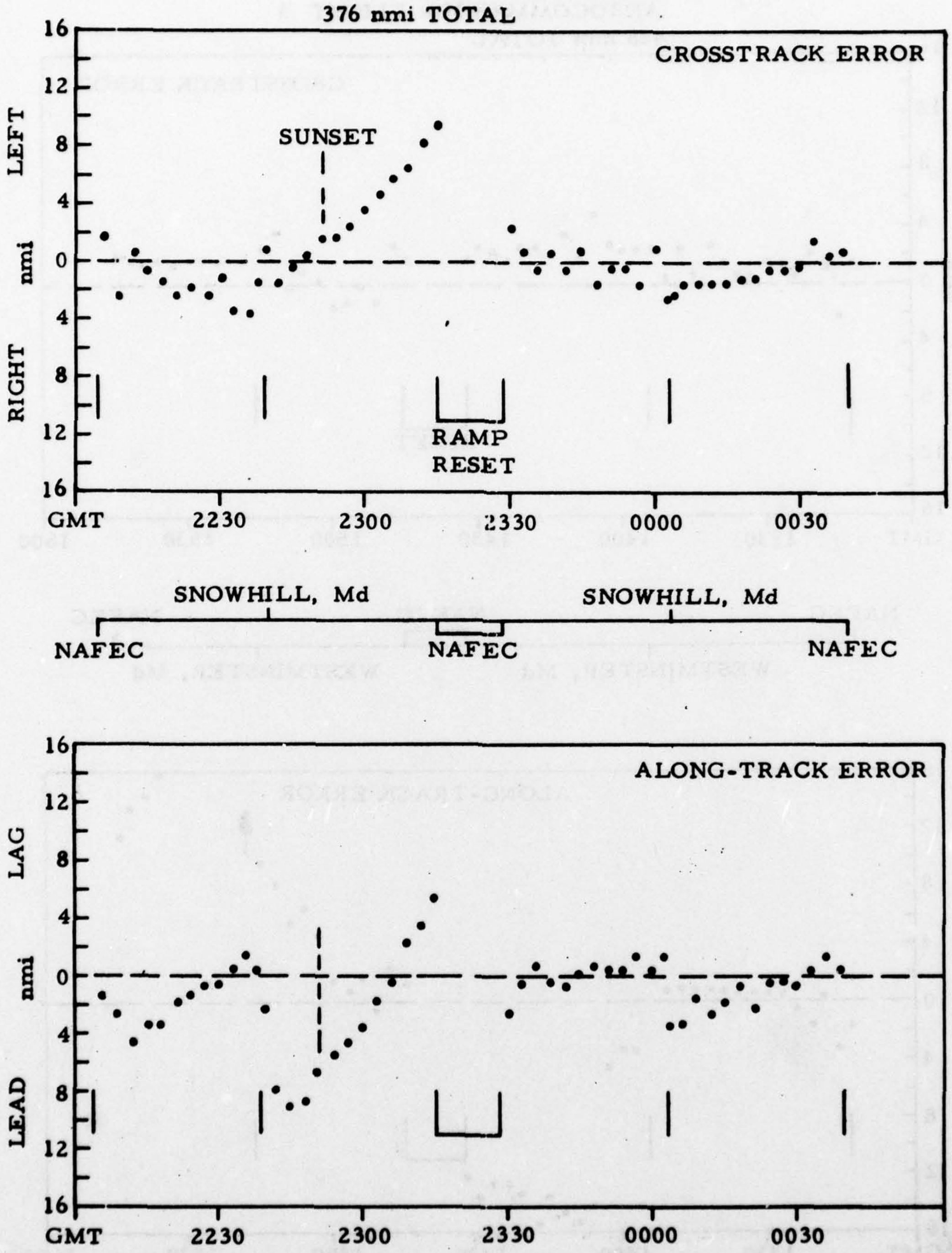
Random samples collected during all flight legs were plotted to illustrate any overall error trends in the data collected. The deleterious effects of diurnal phase shift upon navigation are apparent on the AeroCommander flight 2.

SEPTEMBER 27, 1974
AEROCOMMANDER FLIGHT 1
94 nmi



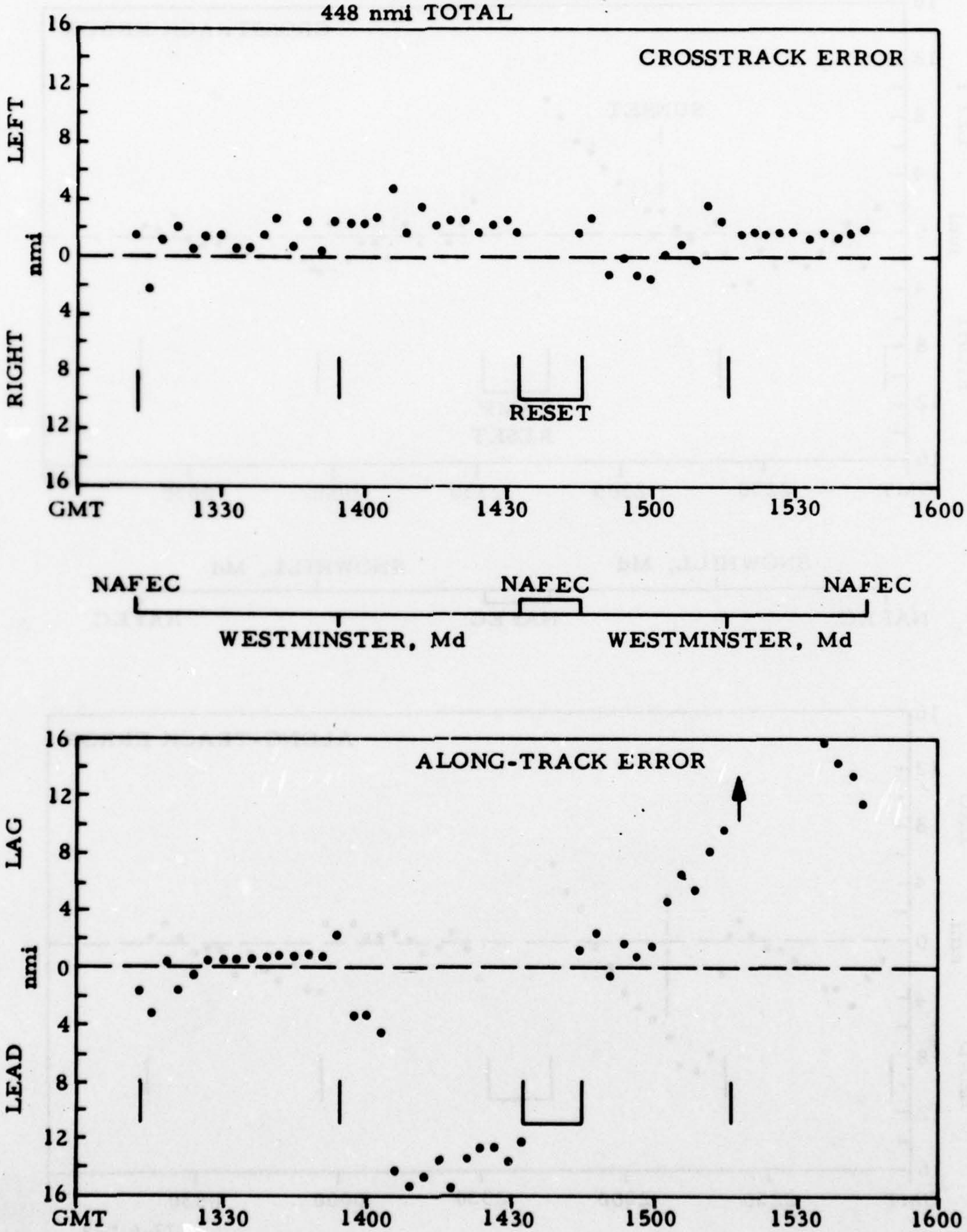
77-6-B-1

OCTOBER 23, 1974
AEROCOMMANDER FLIGHT 2
376 nmi TOTAL



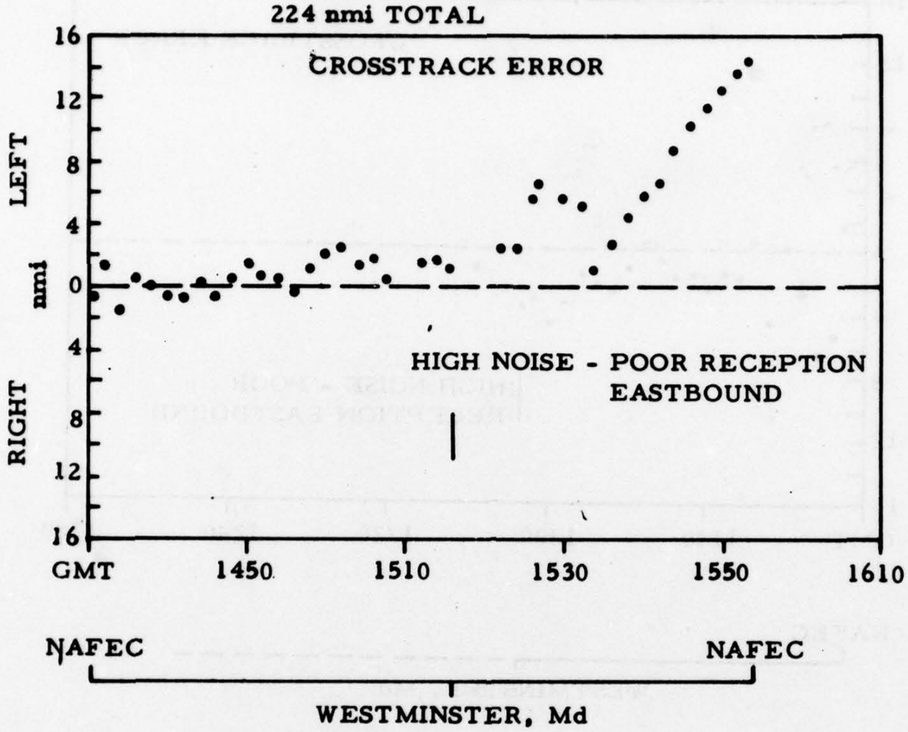
77-6-B-2

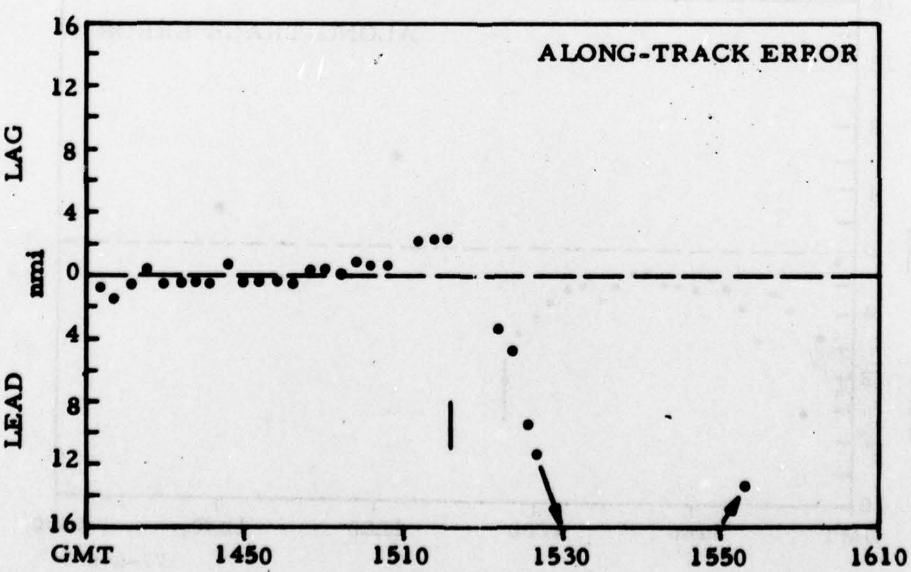
OCTOBER 24, 1974
AEROCOMMANDER FLIGHT 3
448 nmi TOTAL



77-6-B-3

OCTOBER 25, 1974
AEROCOMMANDER FLIGHT 4
224 nmi TOTAL

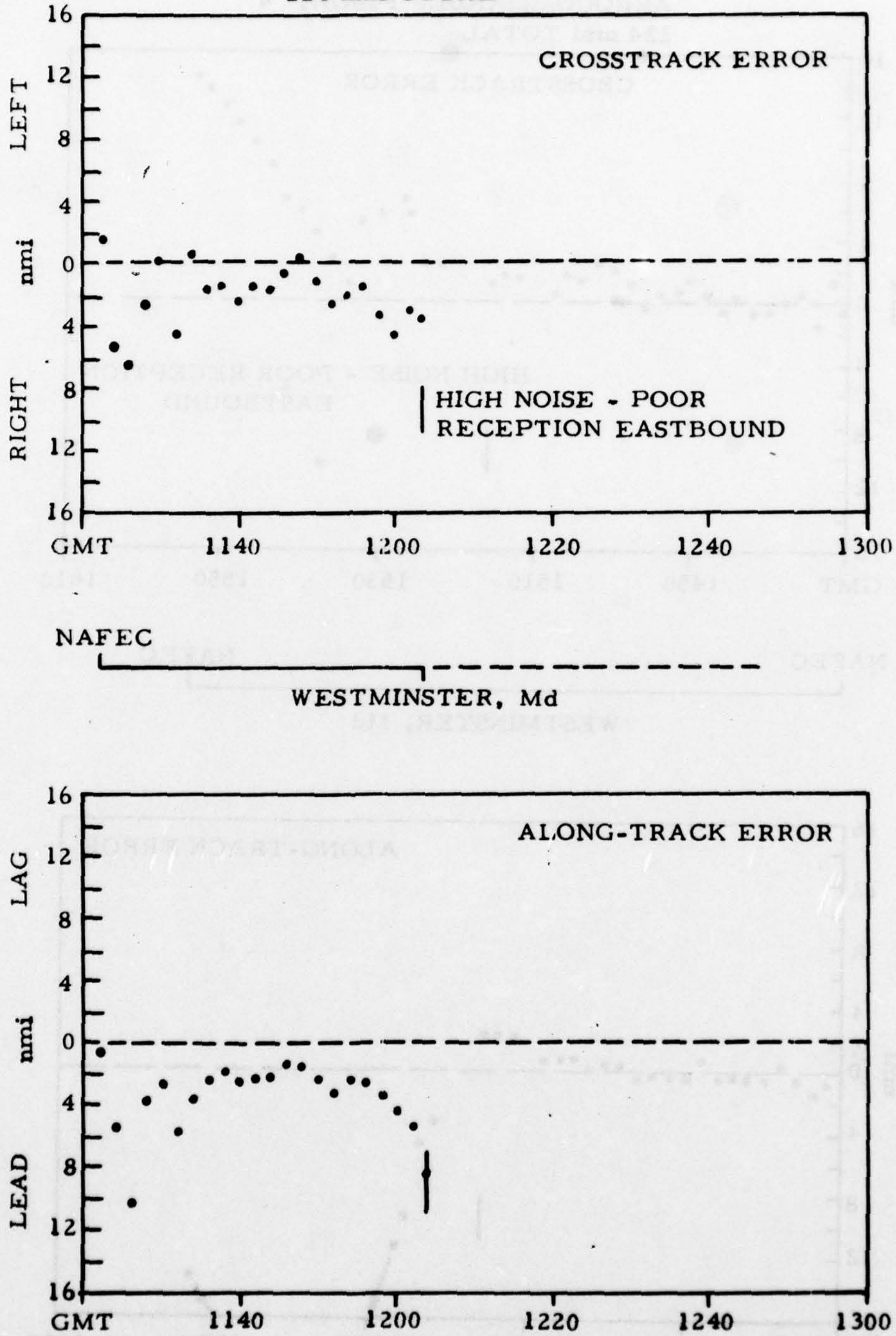




77-6-B-4

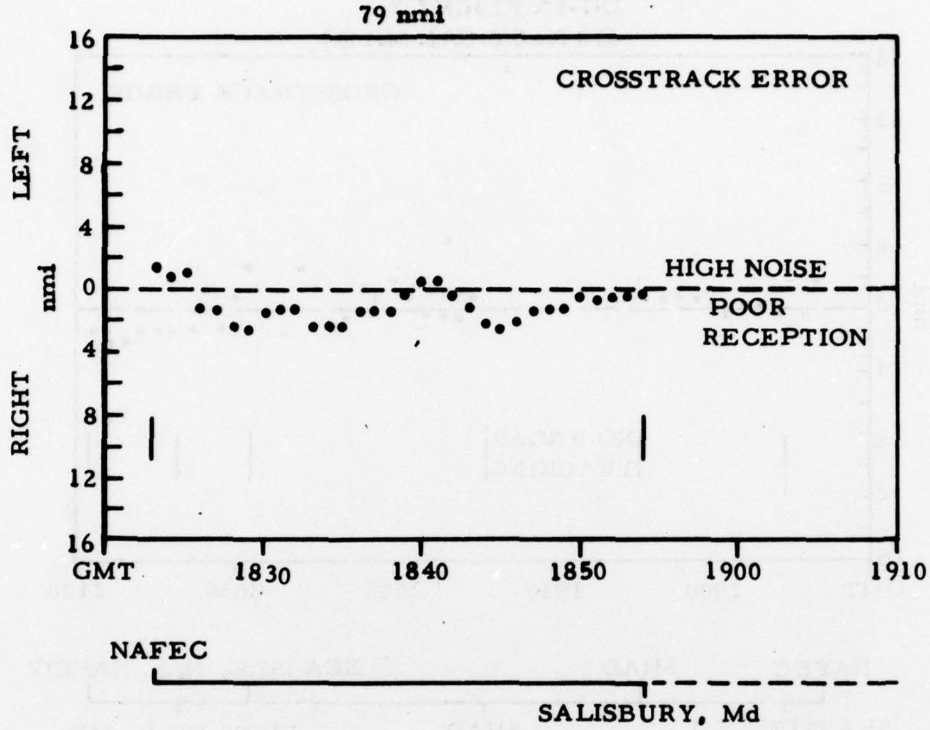
44

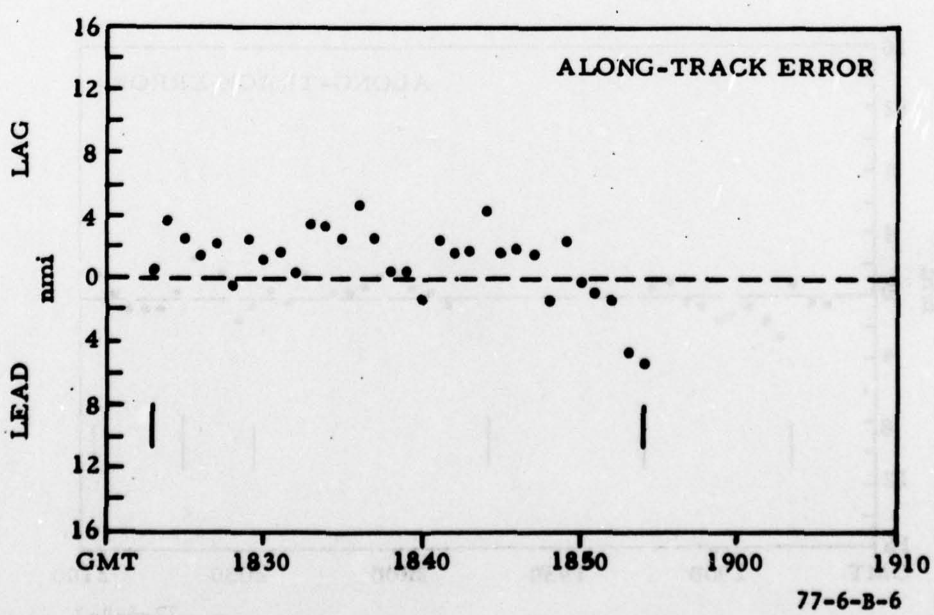
NOVEMBER 22, 1974
AEROCOMMANDER FLIGHT 5
224 nmi TOTAL



77-6-B-5

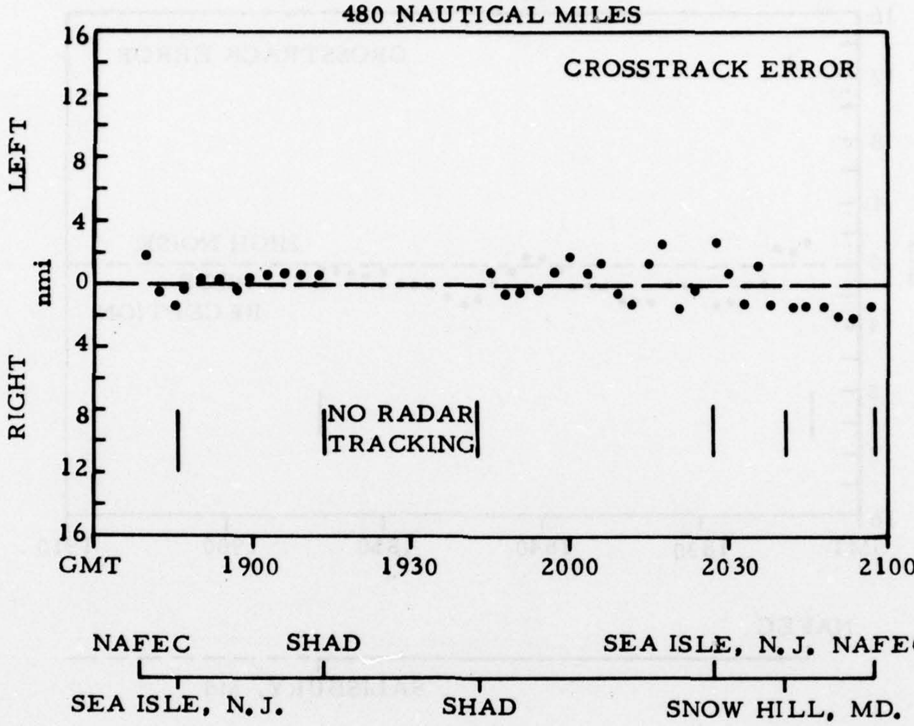
DECEMBER 11, 1974
AEROCOMMANDER FLIGHT 6
79 nmi

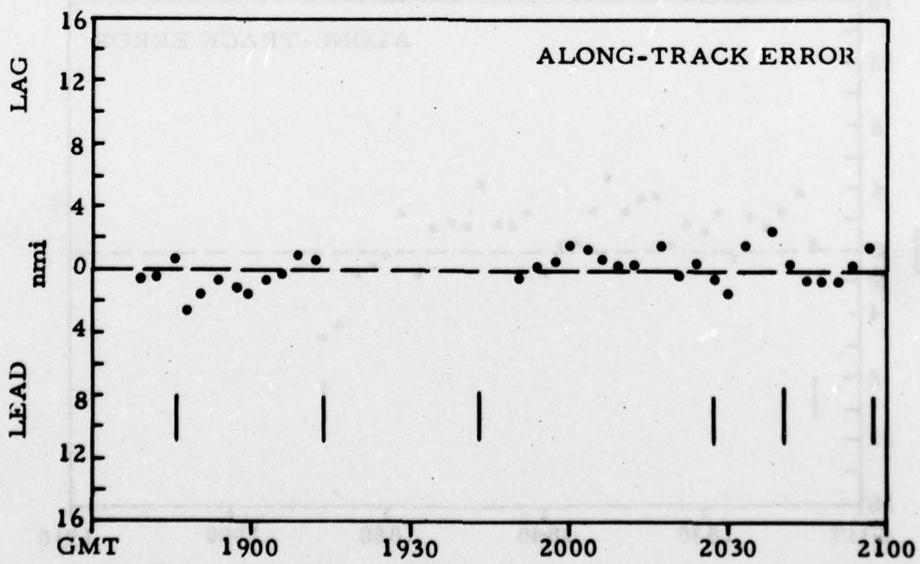




46

DECEMBER 18, 1974
DC-6B FLIGHT 7
480 NAUTICAL MILES

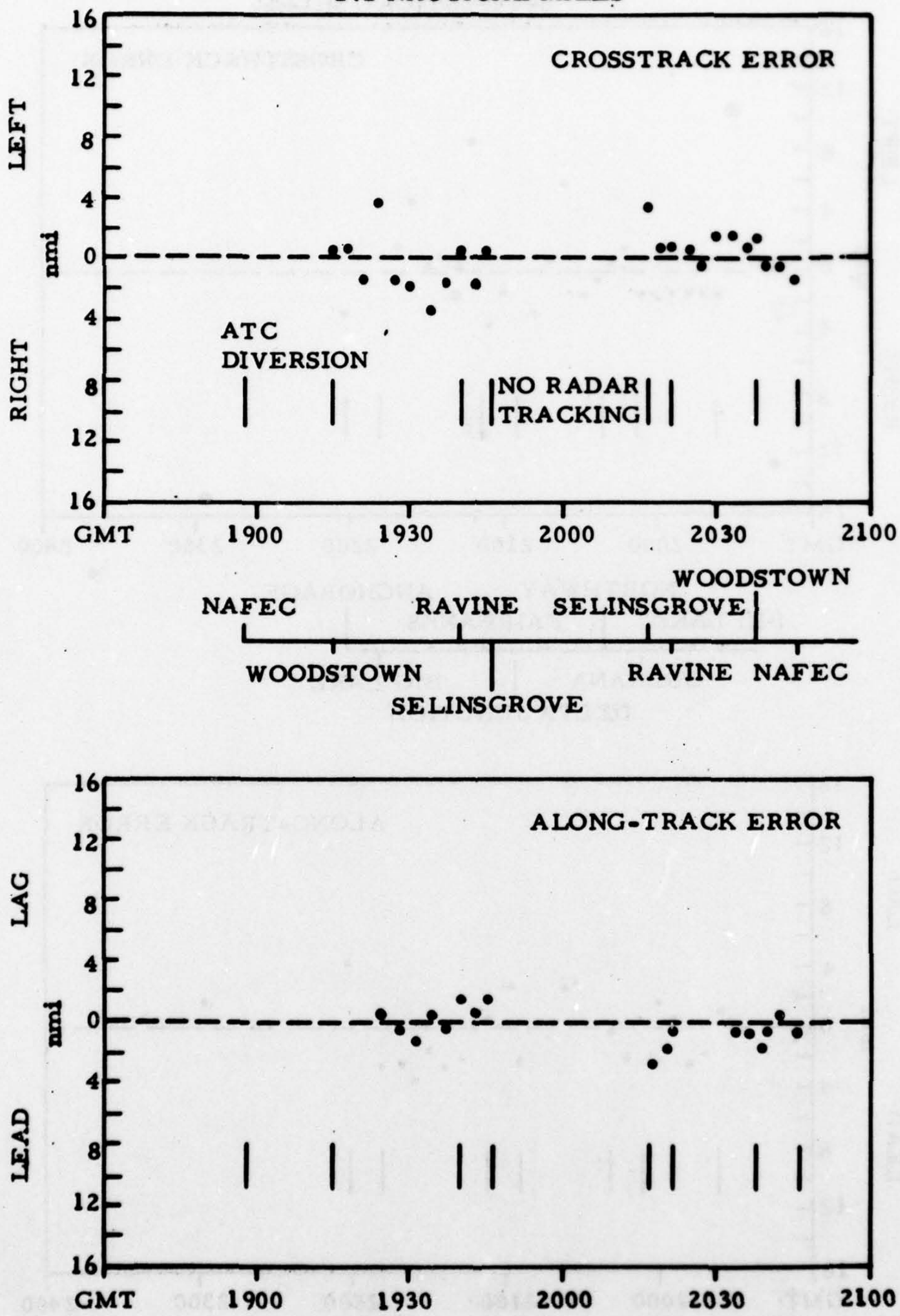




77-6-B-7

47

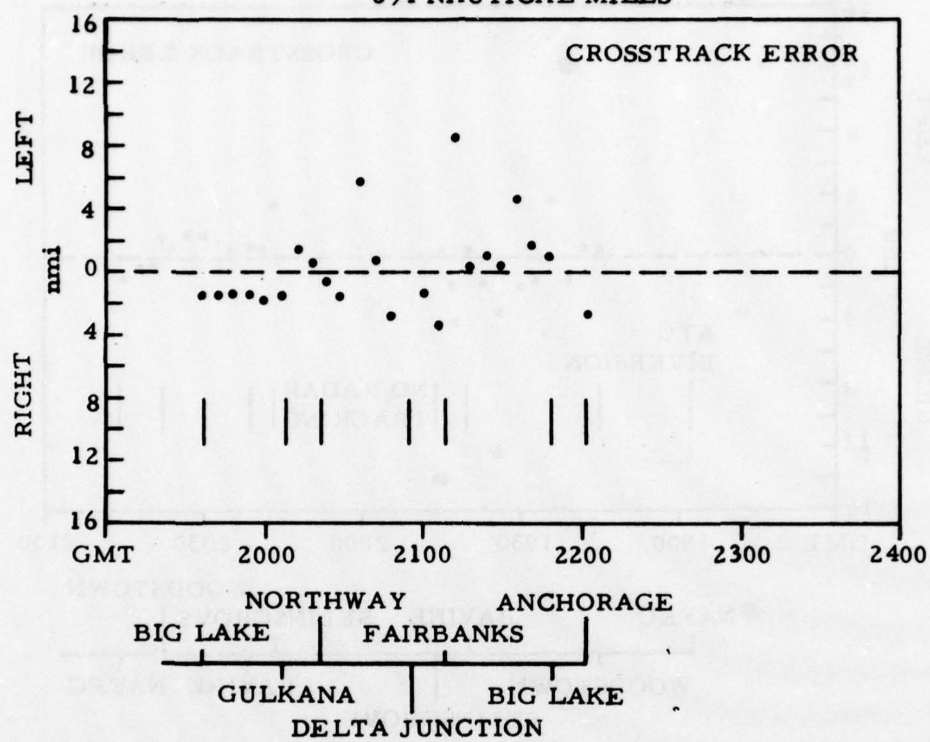
DECEMBER 19, 1974
DC-6B FLIGHT 8
272 NAUTICAL MILES

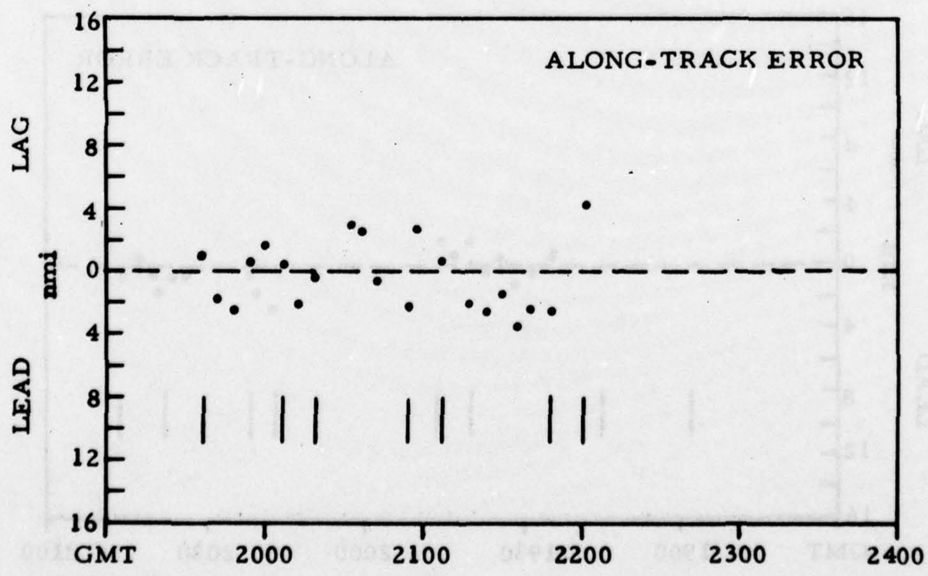


77-6-B-8

48

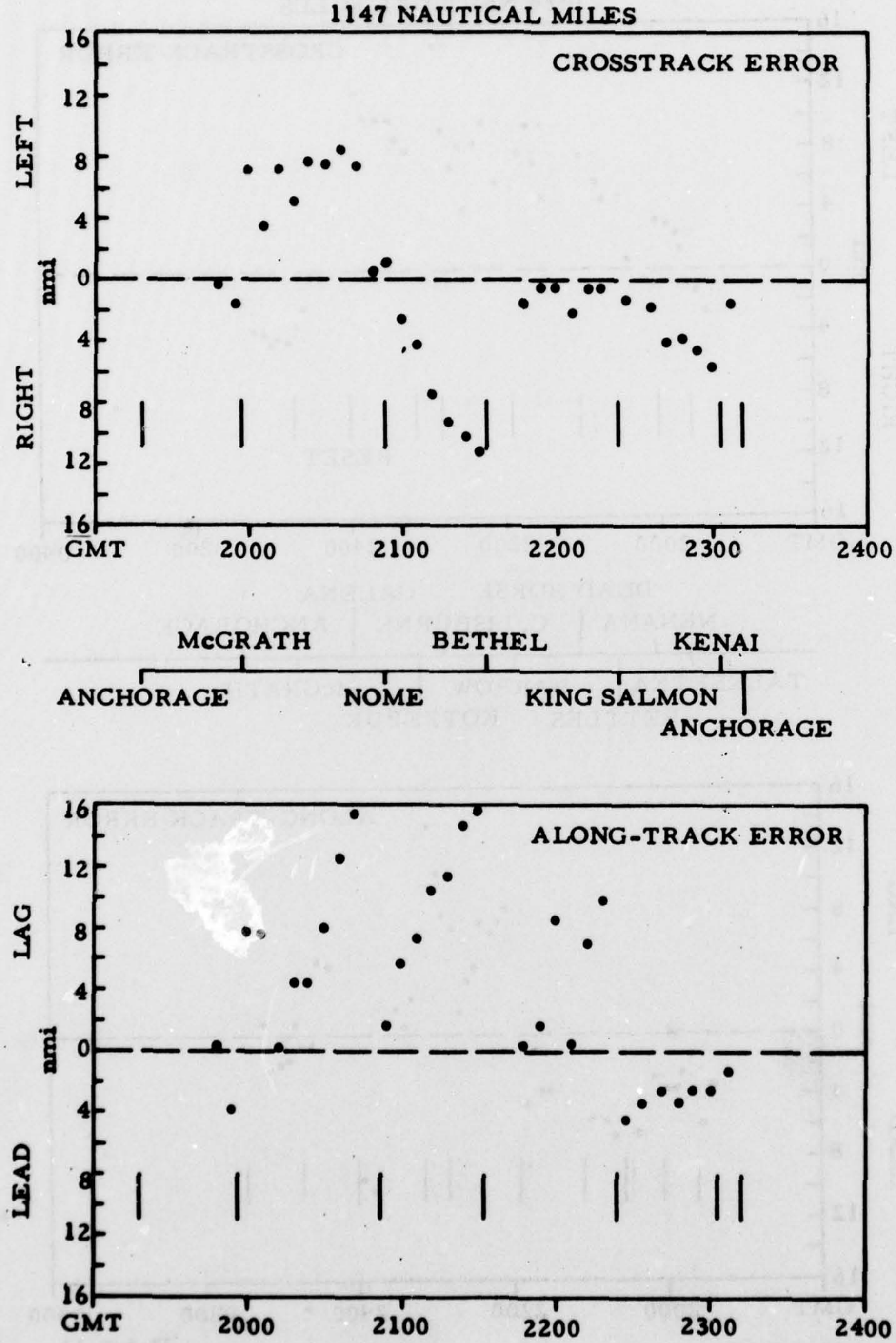
MAY 10, 1975
ALASKAN FLIGHT 1
694 NAUTICAL MILES



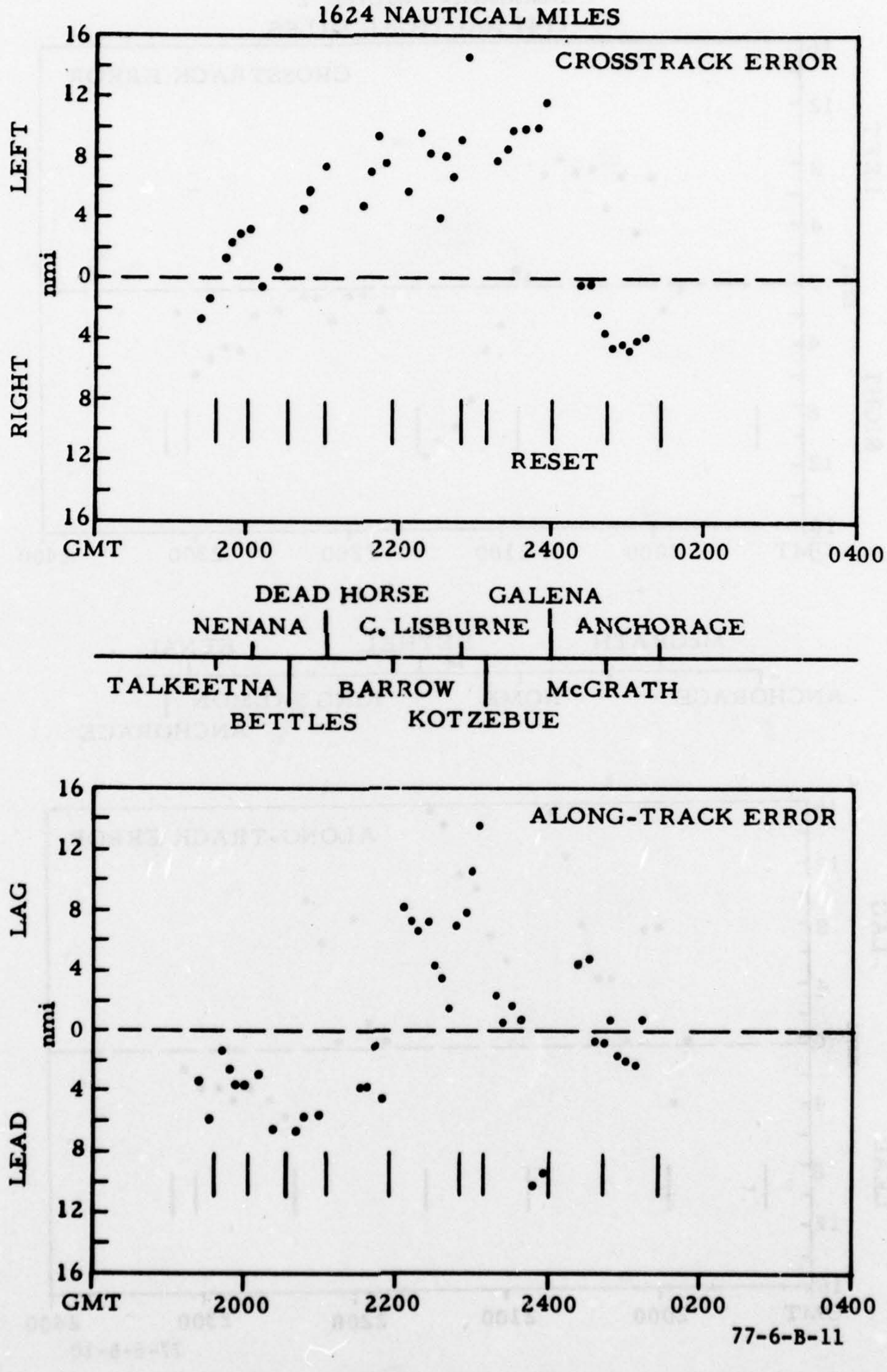


77-6-B-9

MAY 12, 1975
ALASKAN FLIGHT 2
1147 NAUTICAL MILES

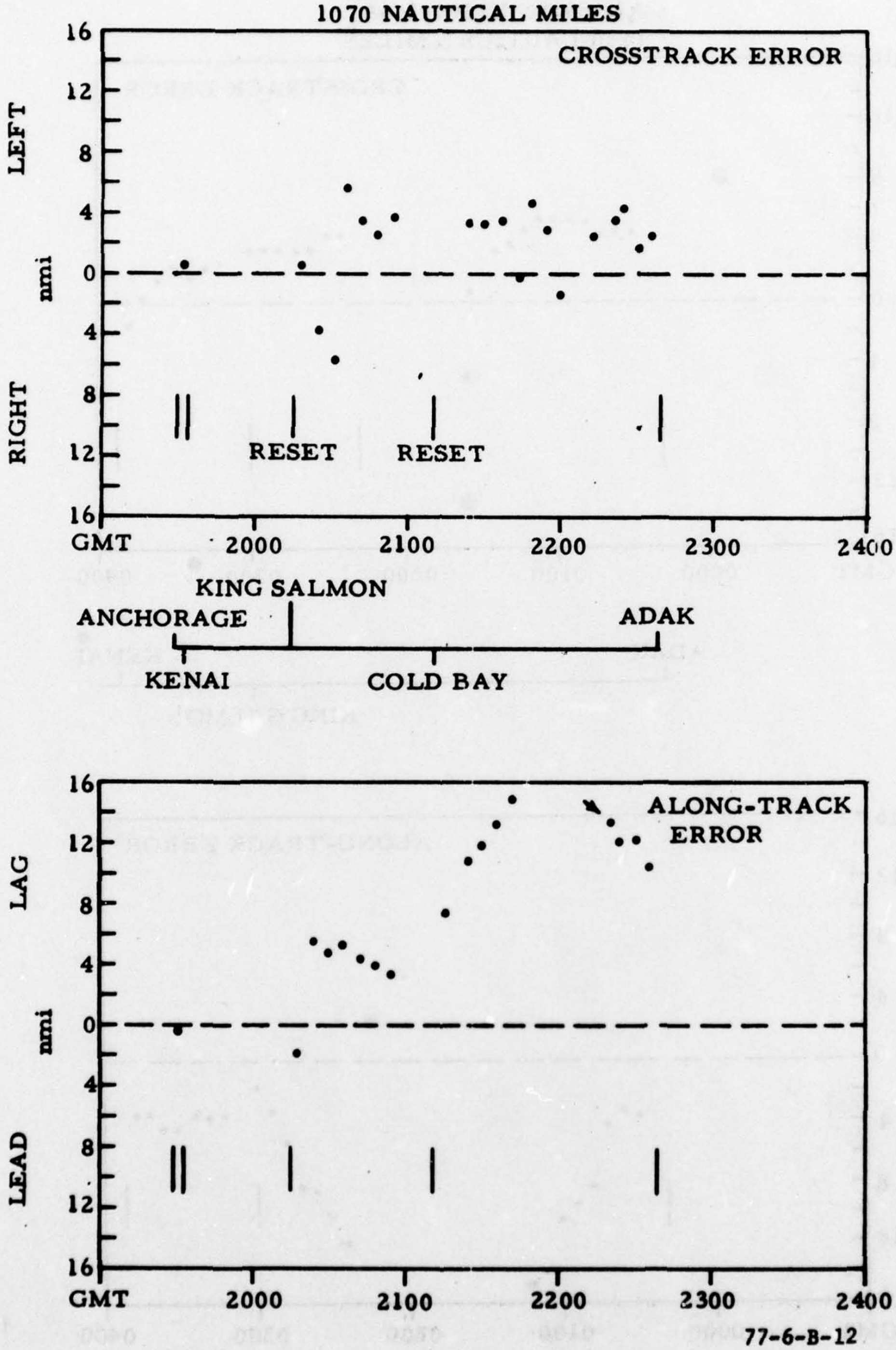


MAY 13, 1975
ALASKAN FLIGHT 3
1624 NAUTICAL MILES



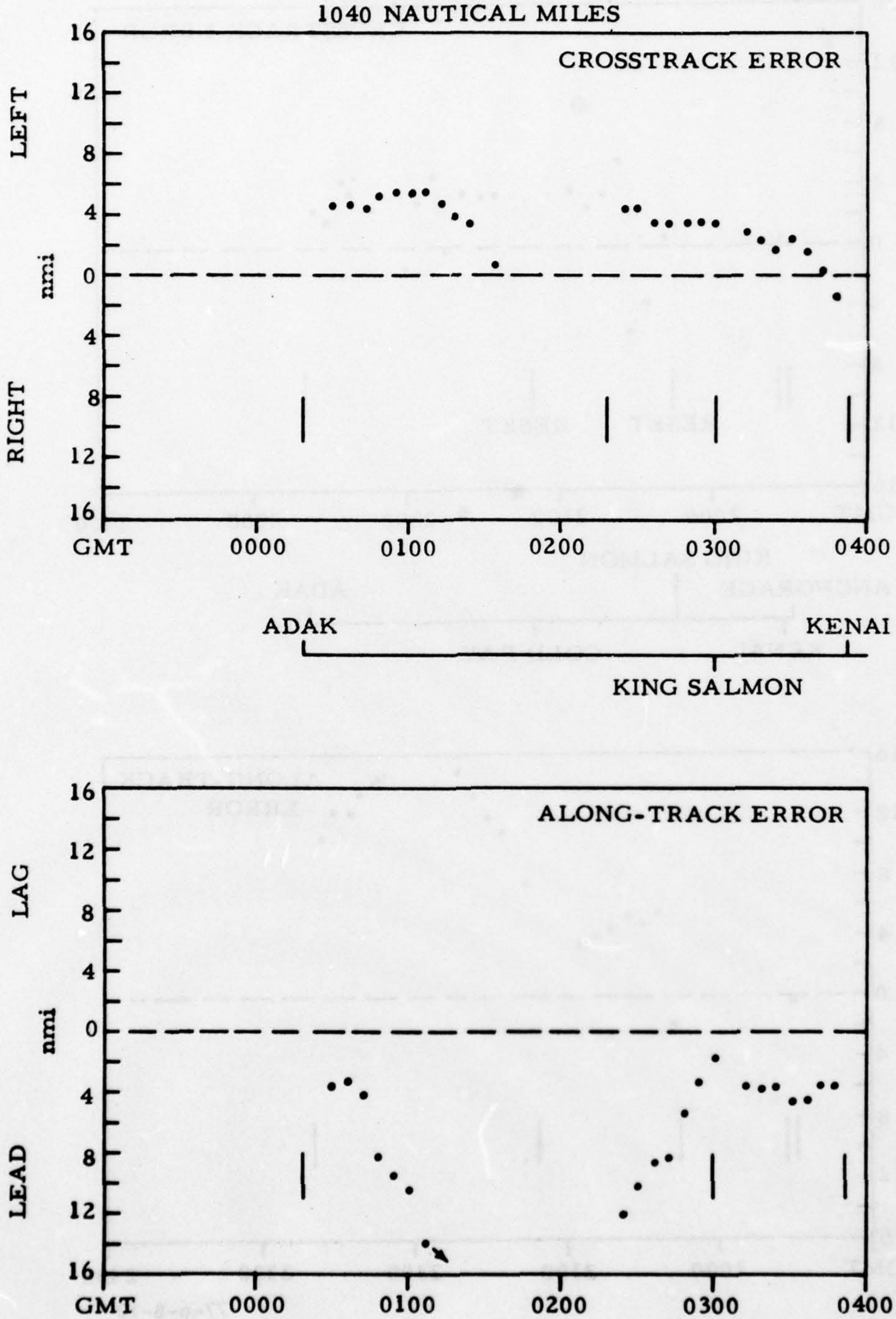
77-6-B-11

MAY 15, 1975
ALASKAN FLIGHT 4
1070 NAUTICAL MILES

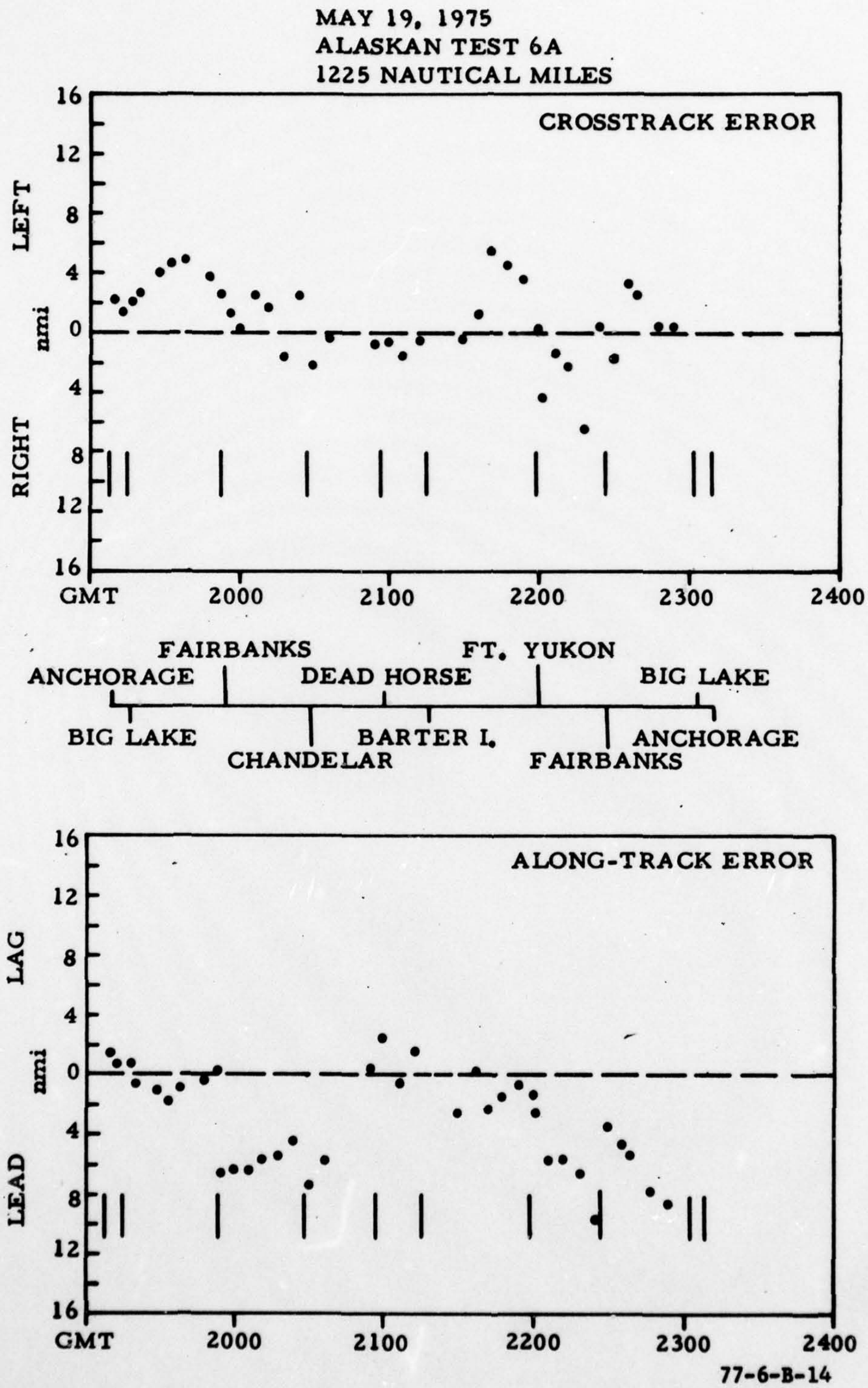


77-6-B-12

MAY 16, 1975
ALASKAN FLIGHT 5A
1040 NAUTICAL MILES



77-6-B-13


MAY 19, 1975
ALASKAN TEST 6A
1225 NAUTICAL MILES
CROSSTRACK ERROR
LEFT
nmi
RIGHT
16
12
8
4
0
4
8
12
16
GMT
2000
2100
2200
2300
2400
FAIRBANKS
FT. YUKON
ANCHORAGE
DEAD HORSE
BIG LAKE
BIG LAKE
BARTER I.
ANCHORAGE
CHANDELAR
FAIRBANKS
ALONG-TRACK ERROR
LAG
nmi
LEAD
16
12
8
4
0
4
8
12
16
GMT
2000
2100
2200
2300
2400
77-6-B-14

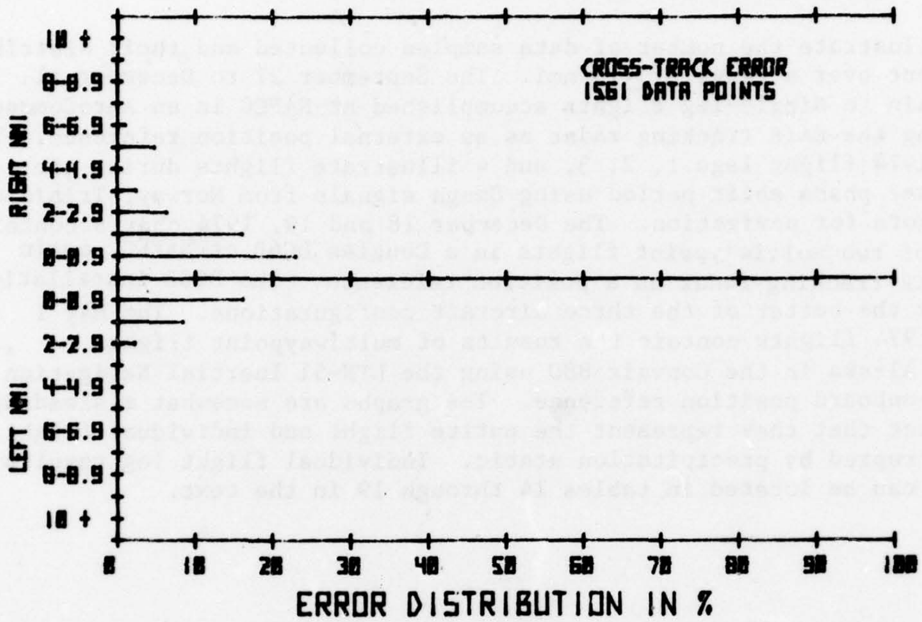
54

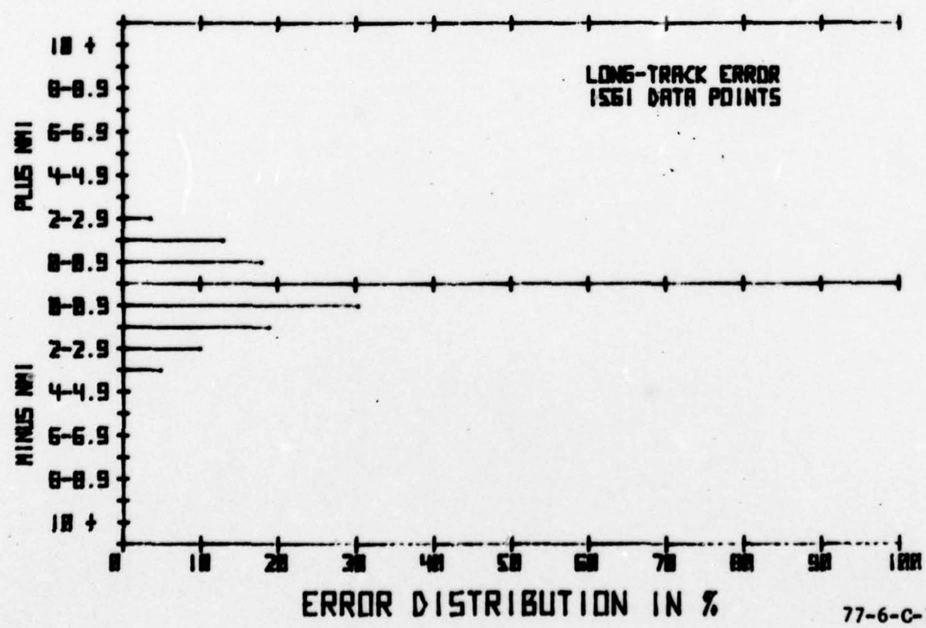
APPENDIX C

ALONG-TRACK AND CROSS-TRACK ERROR DISTRIBUTION

The graphs illustrate the number of data samples collected and their distribution in percent over a range of ±10 nmi. The September 27 to December 11, 1974 flights pertain to single-leg flights accomplished at NAFEC in an AeroCommander aircraft using the EAIR tracking radar as an external position reference. The October 23, 1974 flight legs 1, 2, 3, and 4 illustrate flights during the evening diurnal phase shift period using Omega signals from Norway, Trinidad, and North Dakota for navigation. The December 18 and 19, 1974 charts contain the results of two multiwaypoint flights in a Douglas DC6B at NAFEC, again using the EAIR tracking radar as a position reference. The DC6B installation was obviously the better of the three aircraft configurations. The May 1 through 19, 1974 flights contain the results of multiwaypoint flights conducted in Alaska in the Convair 880 using the LTN-51 Inertial Navigation System as an onboard position reference. The graphs are somewhat misleading, due to the fact that they represent the entire flight and individual flight legs were disrupted by precipitation static. Individual flight leg results and comments can be located in tables 14 through 19 in the text.

SEPTEMBER 27, 1974
NAFEC - SNOWHILL, Md.

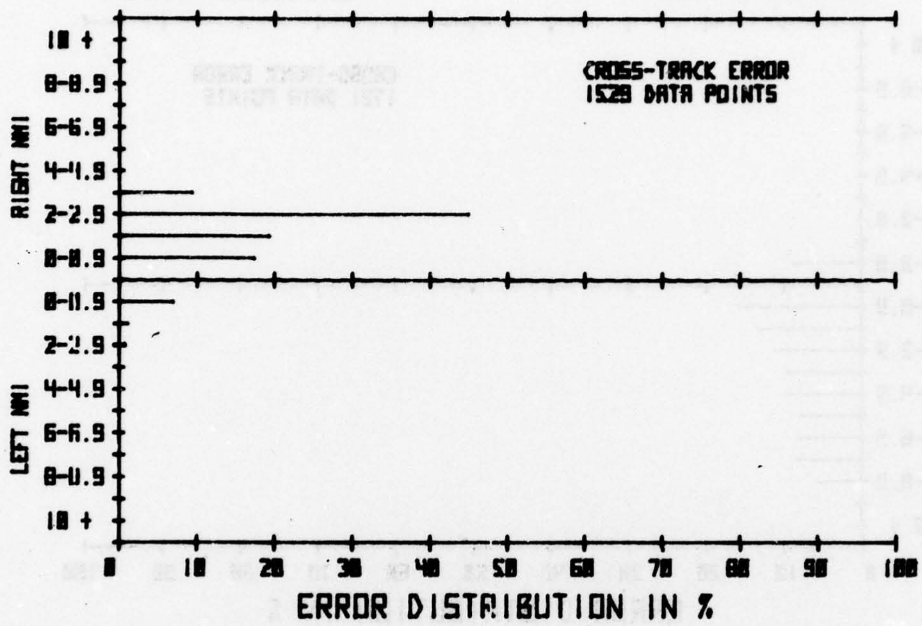


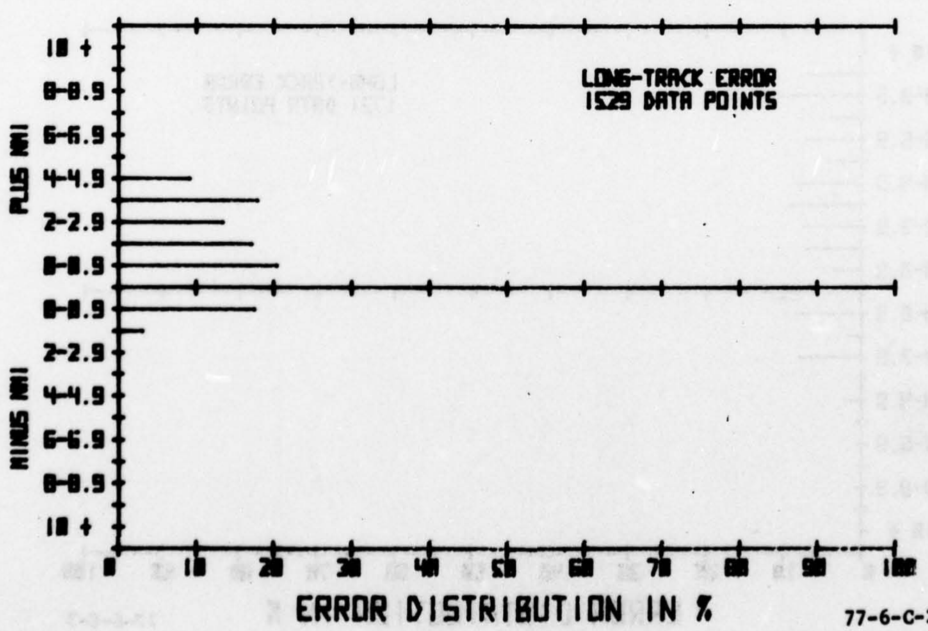


77-6-C-1

OCTOBER 23, 1974
LEG 1
NAFEC - SNOWHILL

PRESUNSET PERIOD

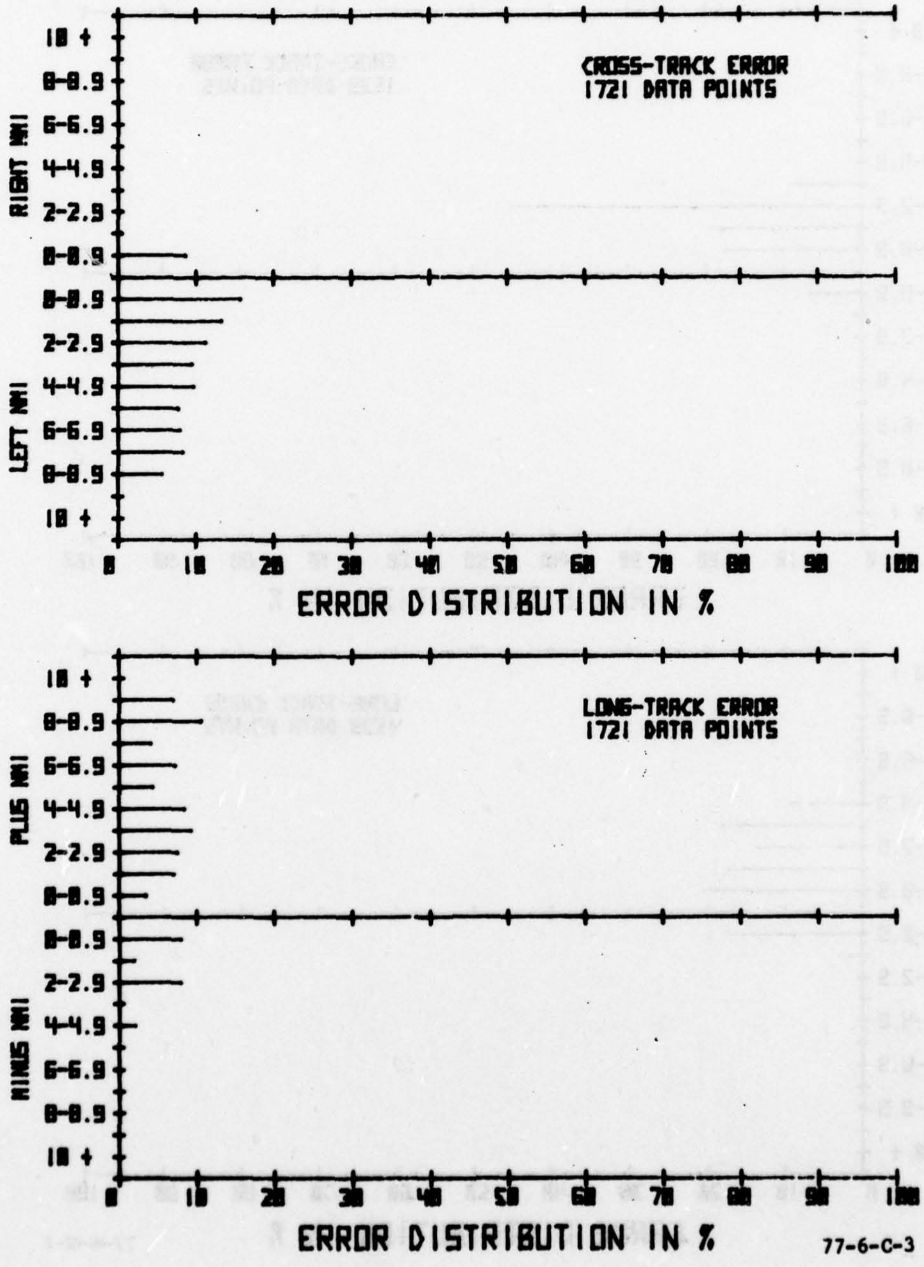




77-6-C-2

OCTOBER 23, 1974
LEG 2
SNOWHILL - NAFEC

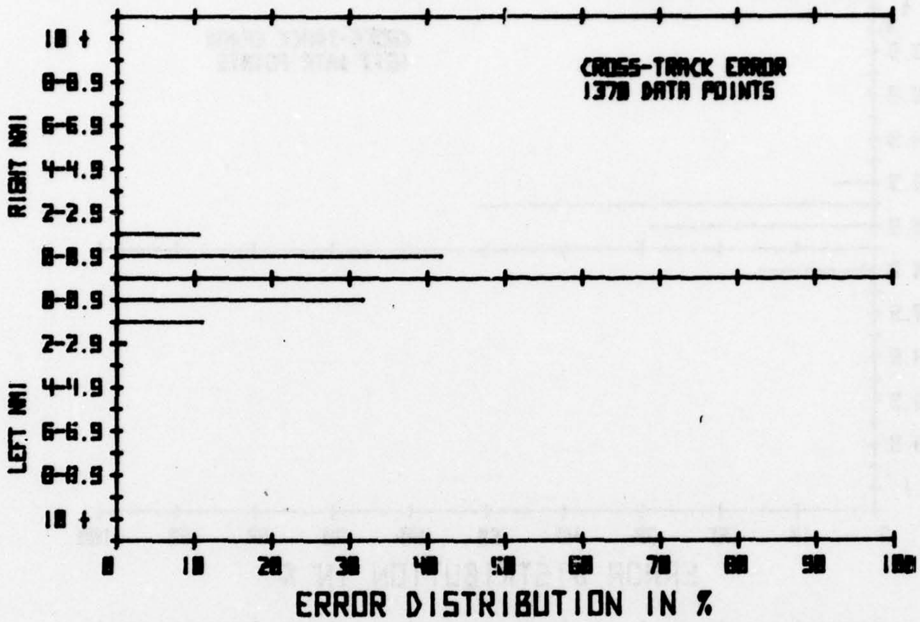
SUNSET PERIOD

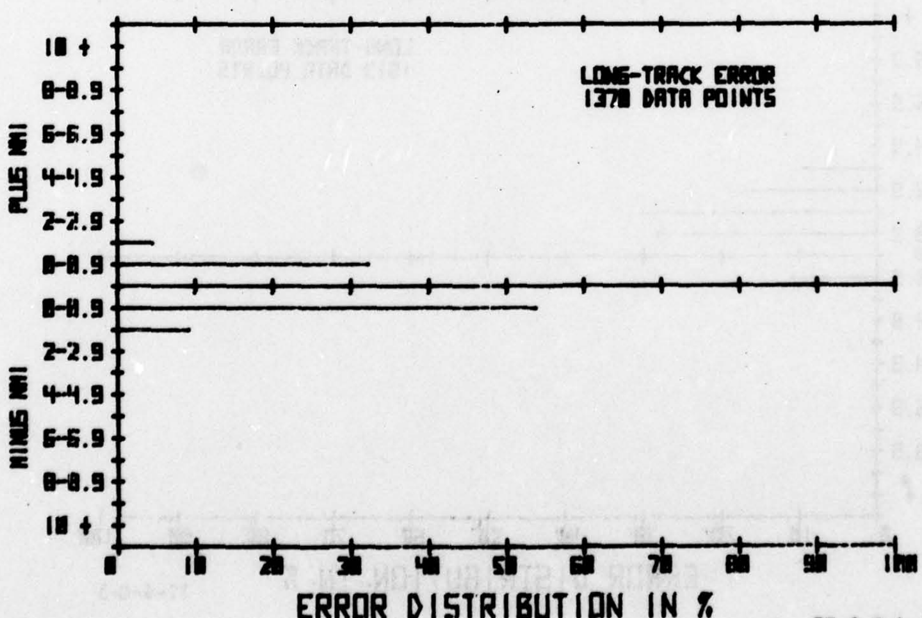


77-6-C-3

POSTSUNSET PERIOD

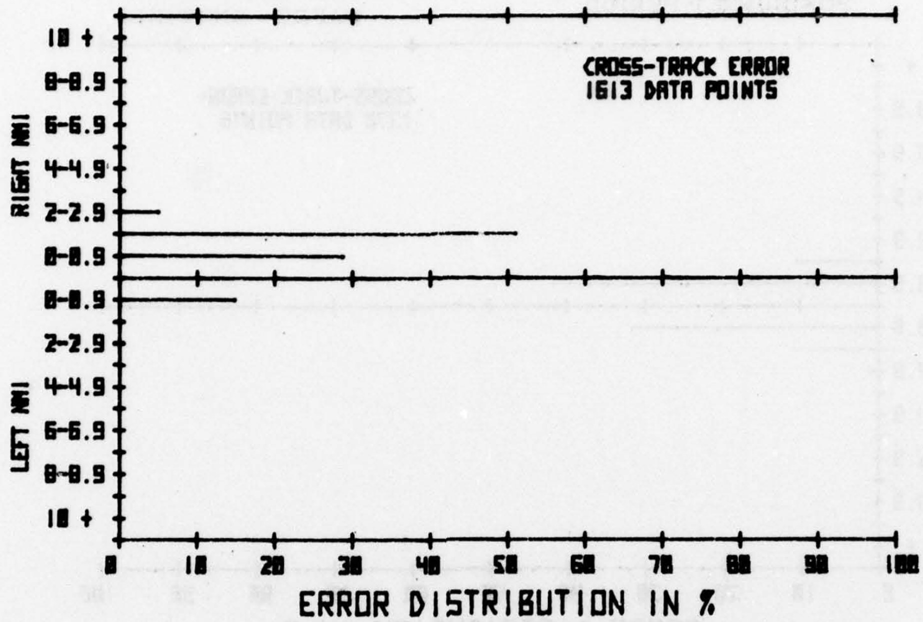
OCTOBER 23, 1974
LEG 3
NAFEC - SNOWHILL

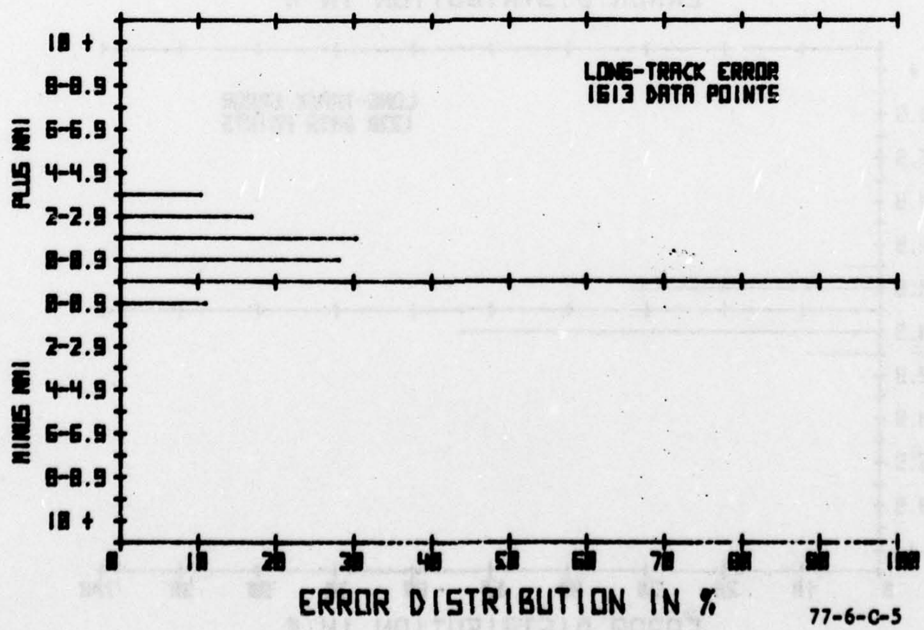




77-6-C-4

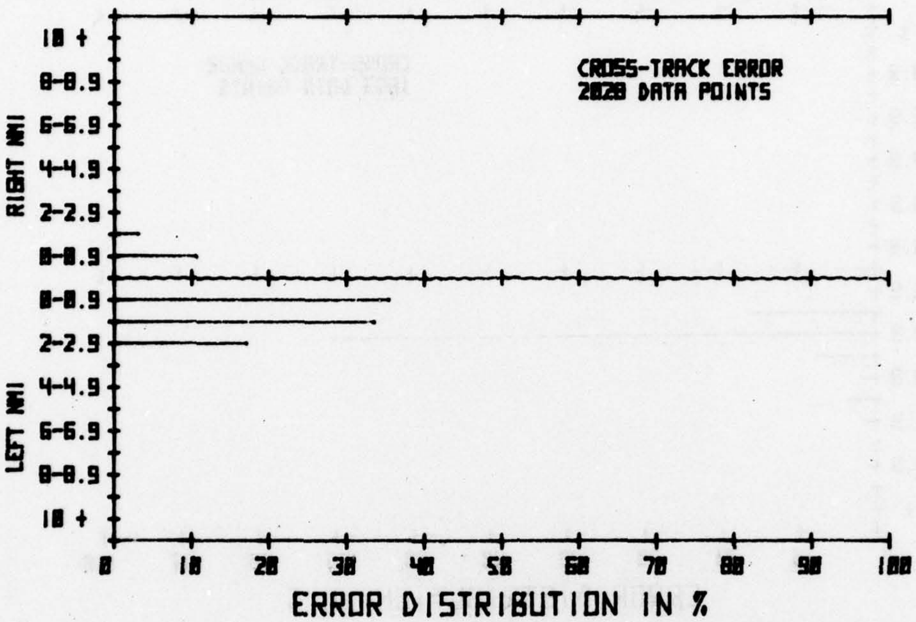
OCTOBER 23, 1974
LEG 4
POSTSUNSET PERIOD SNOWHILL - NAFEC

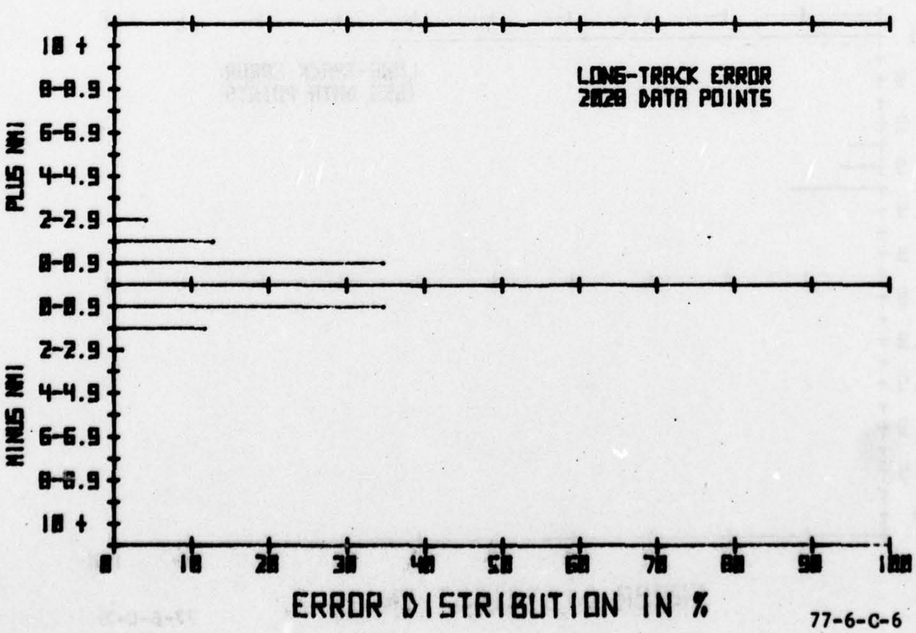




77-6-C-5

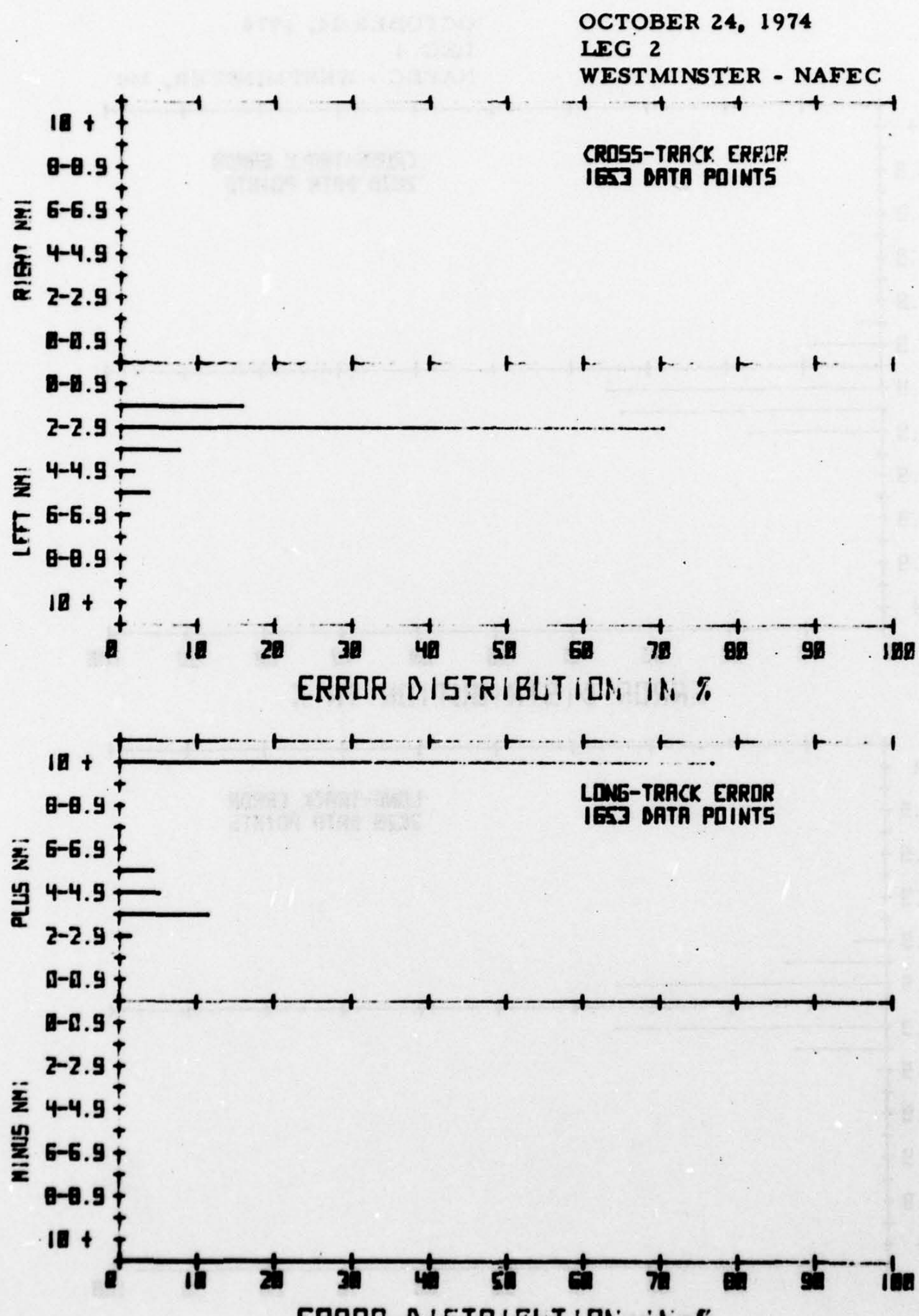
OCTOBER 24, 1974
LEG 1
NAFEC - WESTMINSTER, Md





77-6-C-6

61

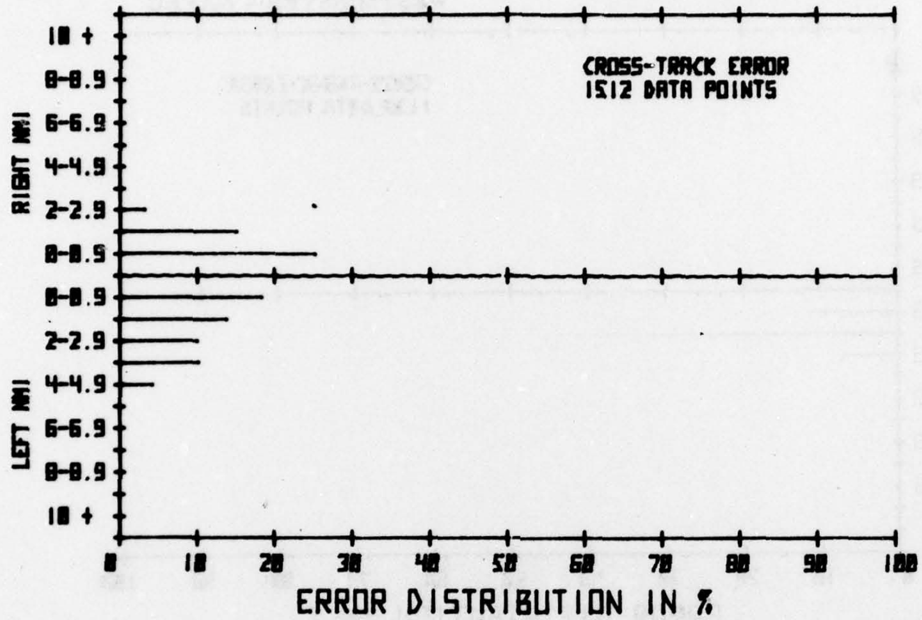


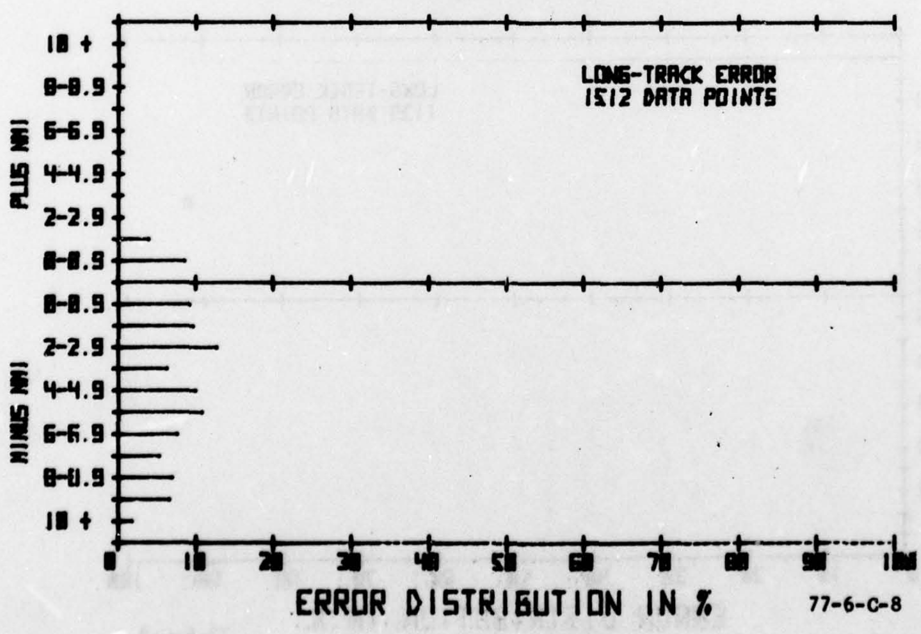
OCTOBER 24, 1974
LEG 2
WESTMINSTER - NAFEC
CROSS-TRACK ERROR
1653 DATA POINTS
RIGHT NMI
LEFT NMI
10 +
8-8.9
6-6.9
4-4.9
2-2.9
0-0.9
0
10
20
30
40
50
60
70
80
90
100
ERROR DISTRIBUTION IN %
LONG-TRACK ERROR
1653 DATA POINTS
PLUS NMI
MINUS NMI
ERROR DISTRIBUTION IN %

77-6-C-7

62

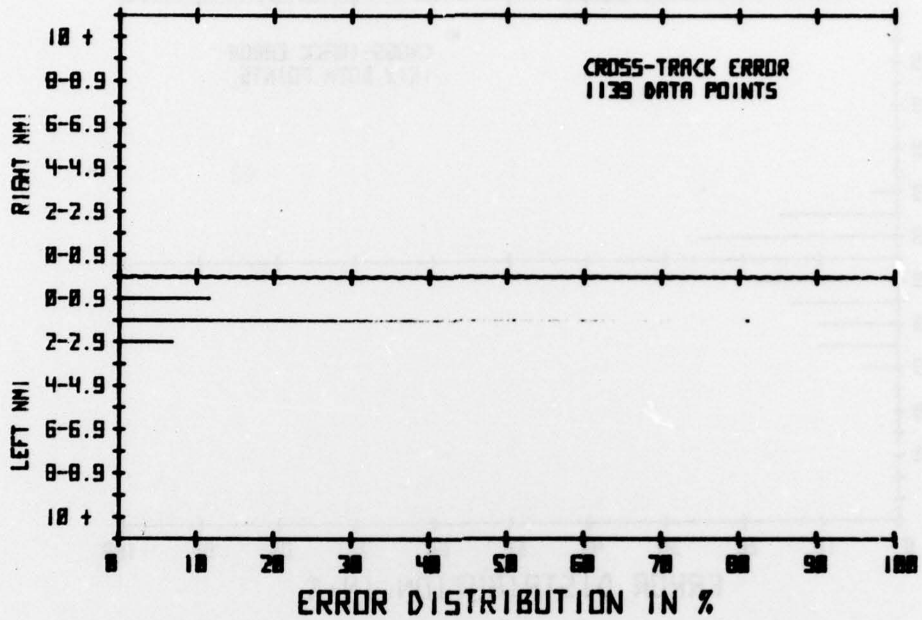
OCTOBER 24, 1974
LEG 3
NAFEC - WESTMINSTER

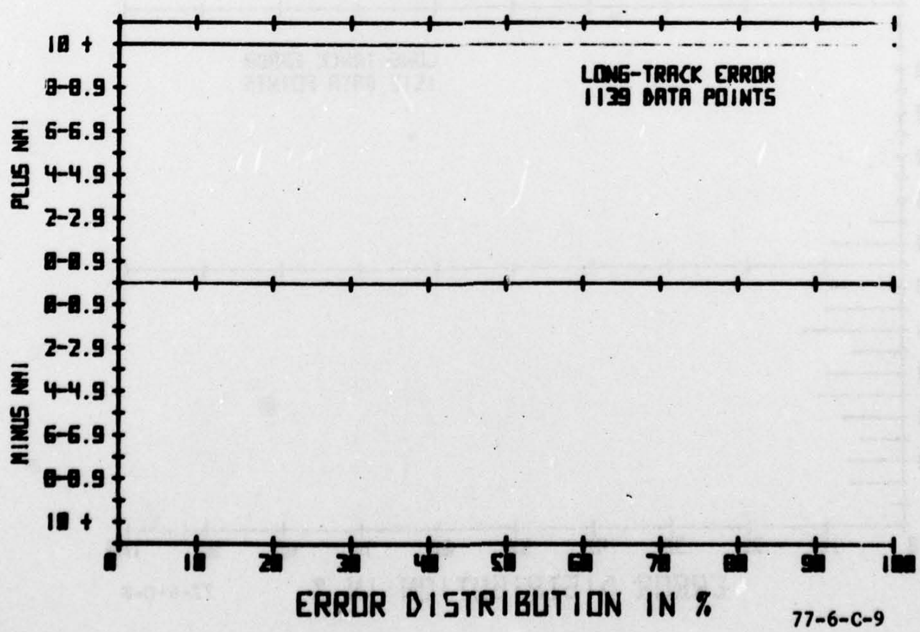




77-6-C-8

OCTOBER 24, 1974
LEG 4
WESTMINSTER - NAFEC

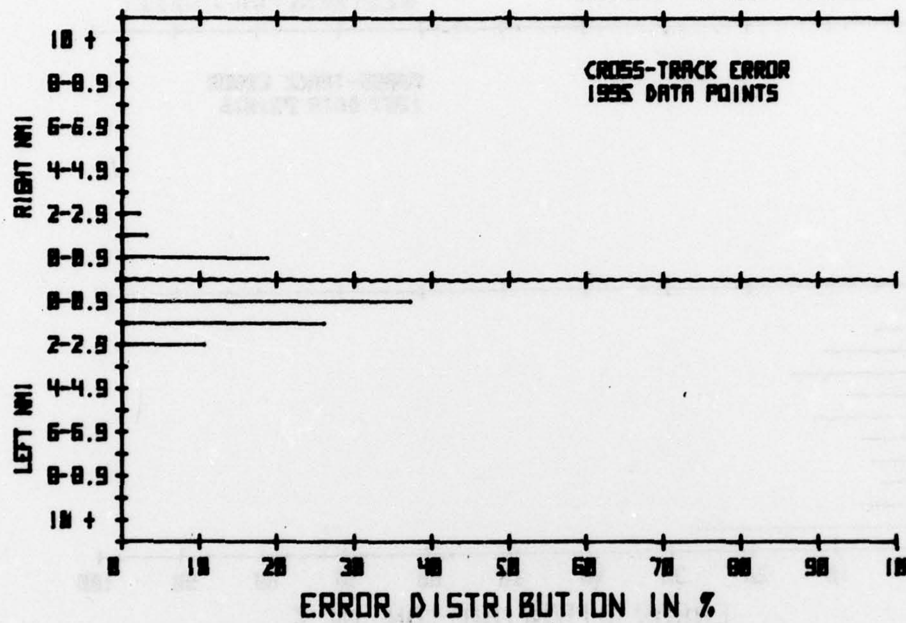


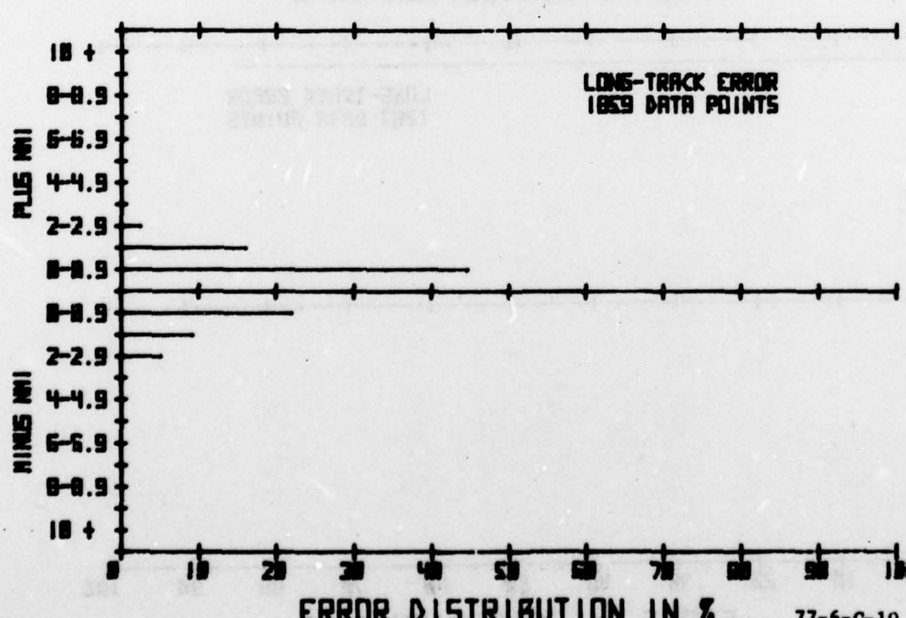


77-6-C-9

64

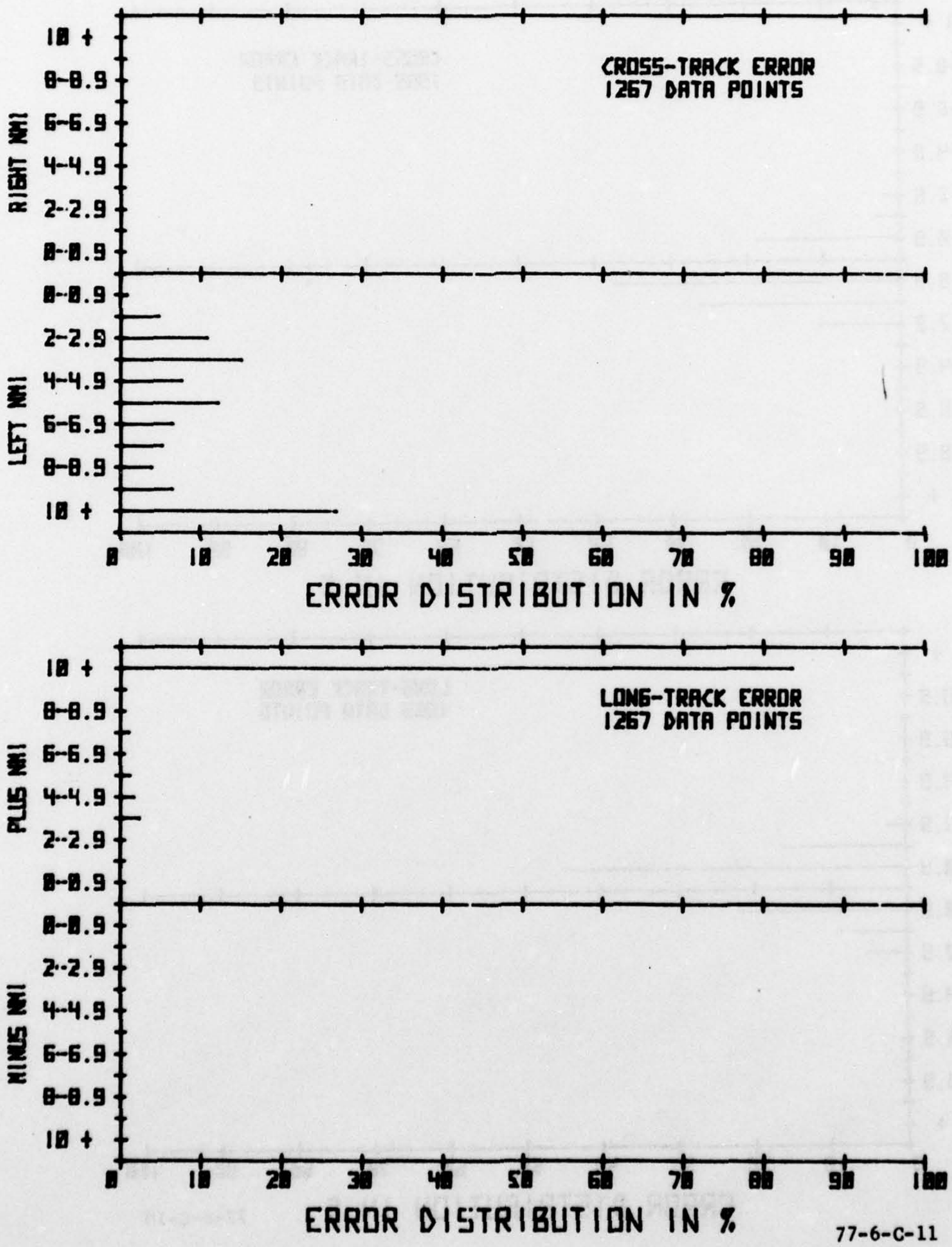
OCTOBER 25, 1974
LEG 1
NAFEC - WESTMINSTER





77-6-C-10

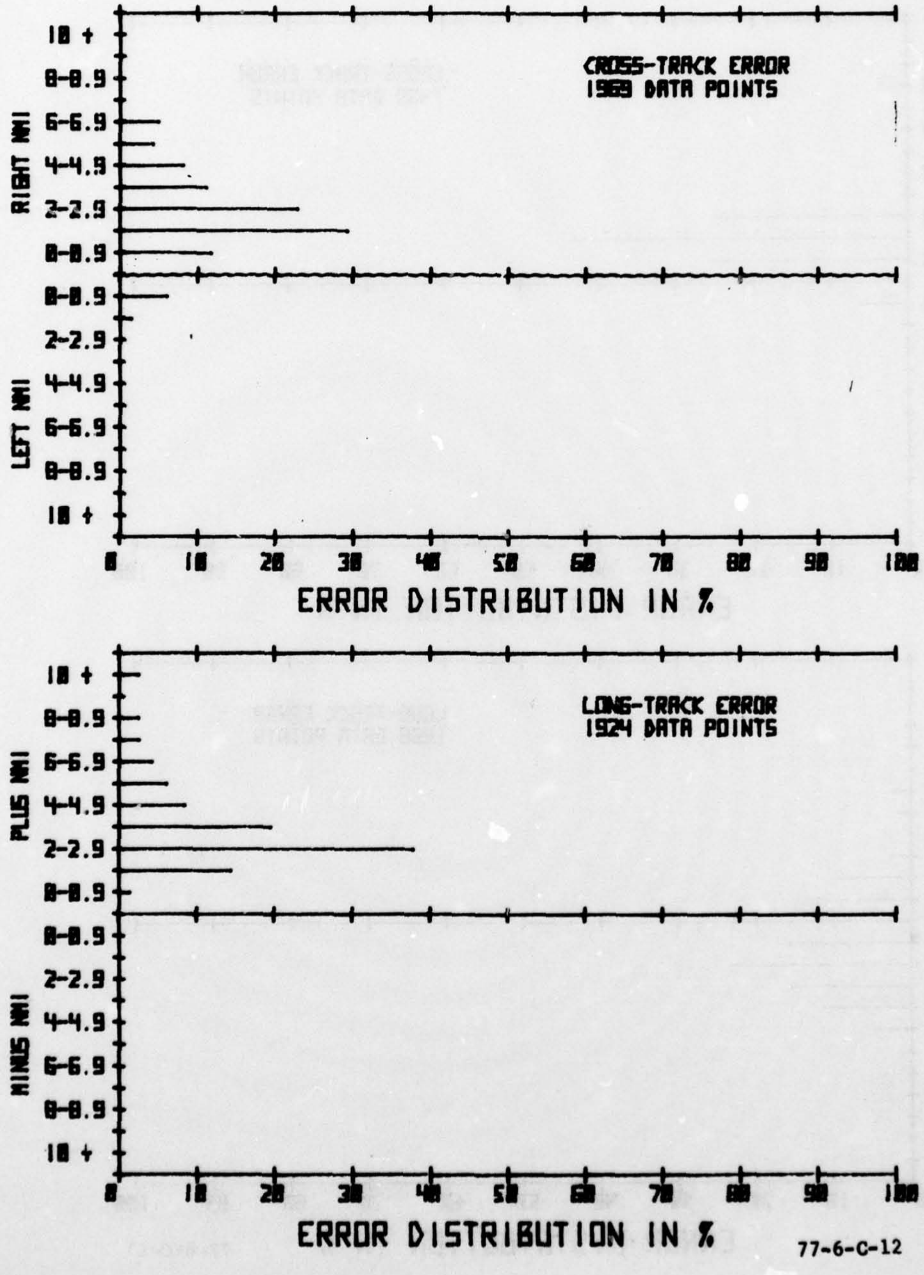
OCTOBER 25, 1974
LEG 2
WESTMINSTER - NAFEC



77-6-C-11

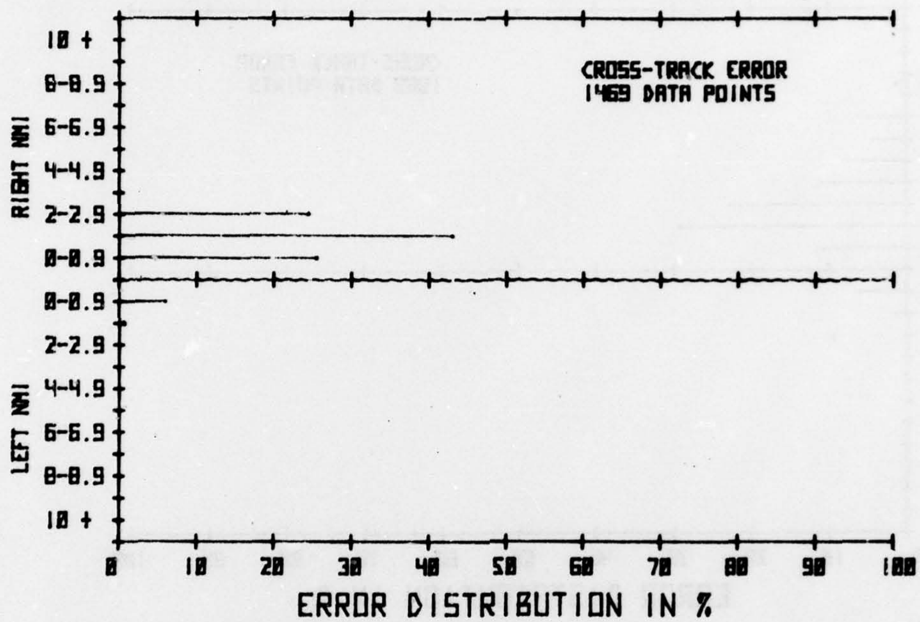
66

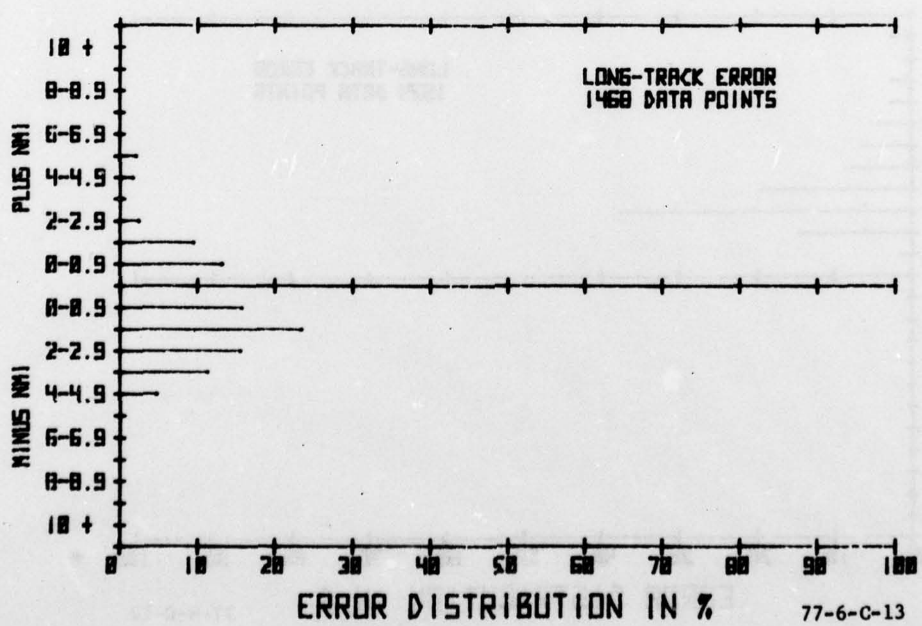
NOVEMBER 22, 1974
LEG 1
NAFEC - WESTMINSTER



77-6-C-12

DECEMBER 11, 1974
LEG 1
NAFEC - SALISBURY, Md

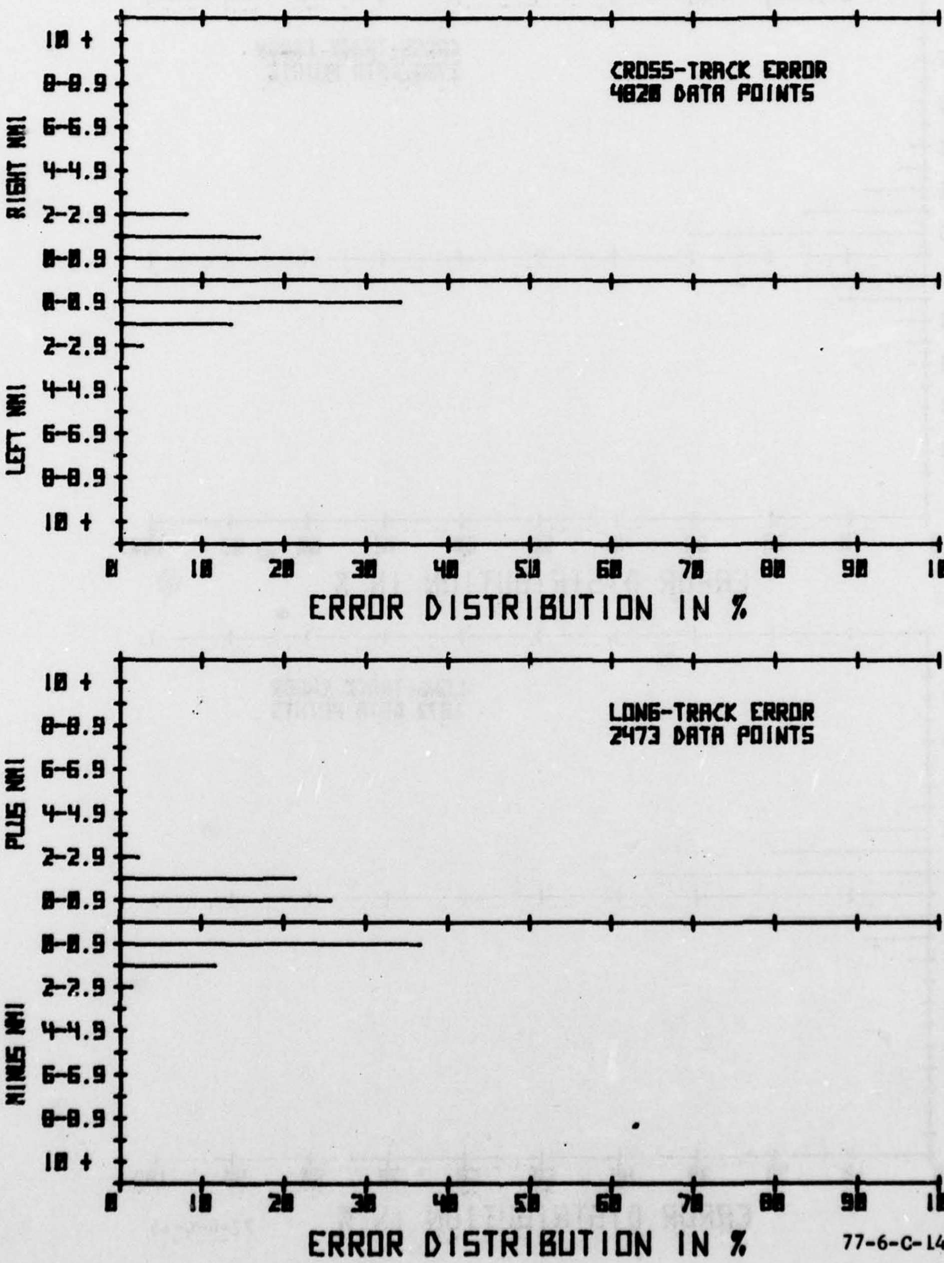




77-6-C-13

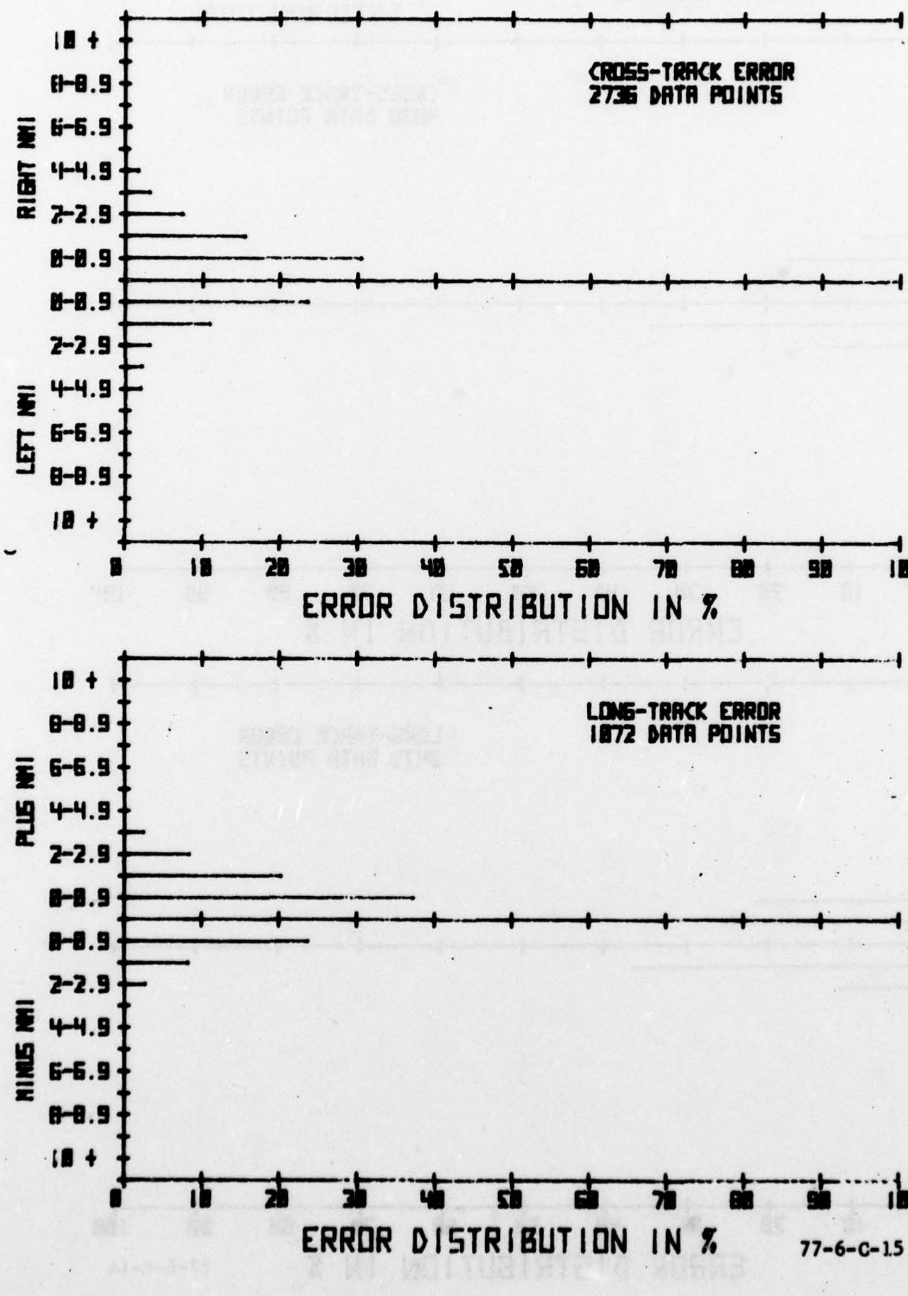
68

DECEMBER 18, 1974
DC6B
ENTIRE FLIGHT



69

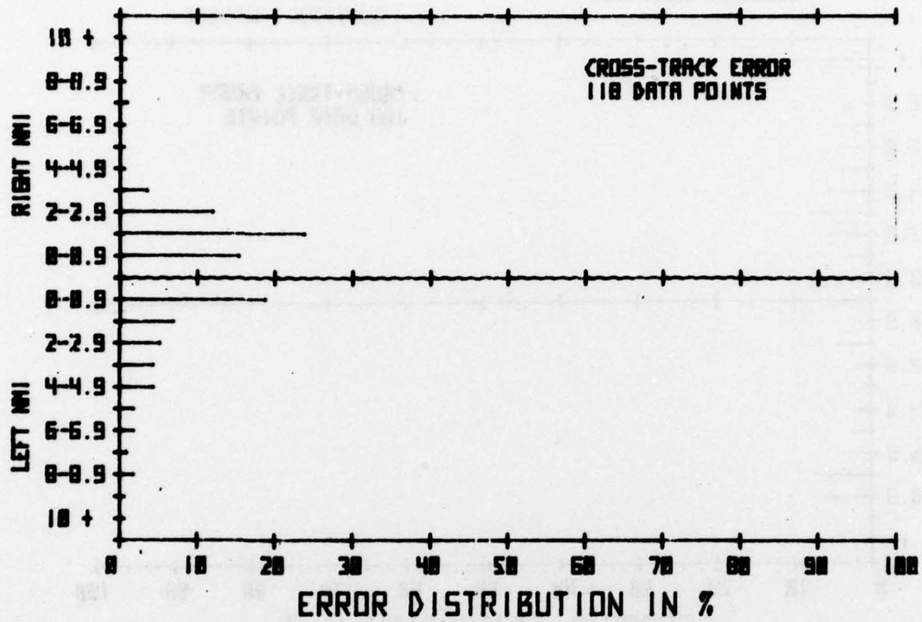
DECEMBER 19, 1974
DC6B
ENTIRE FLIGHT

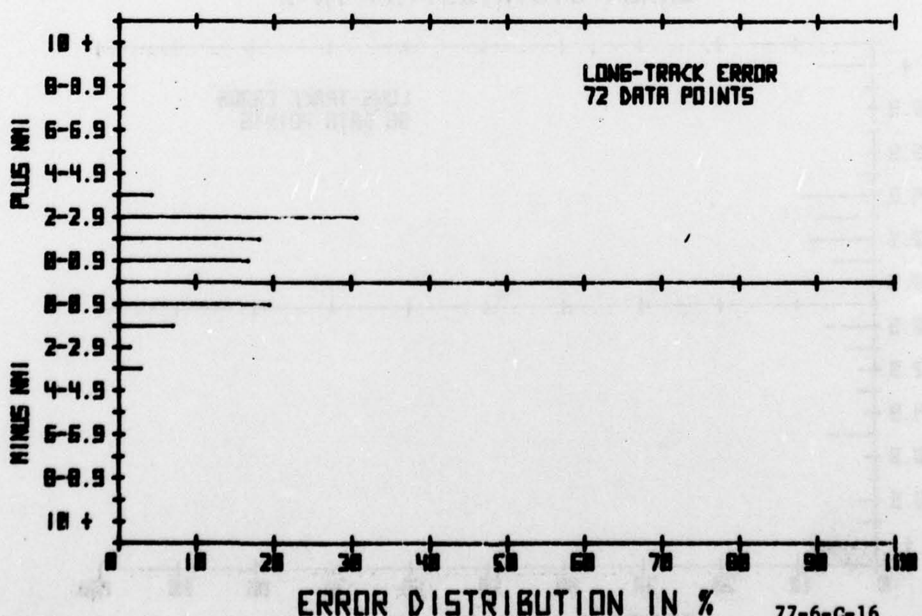


77-6-C-15

70

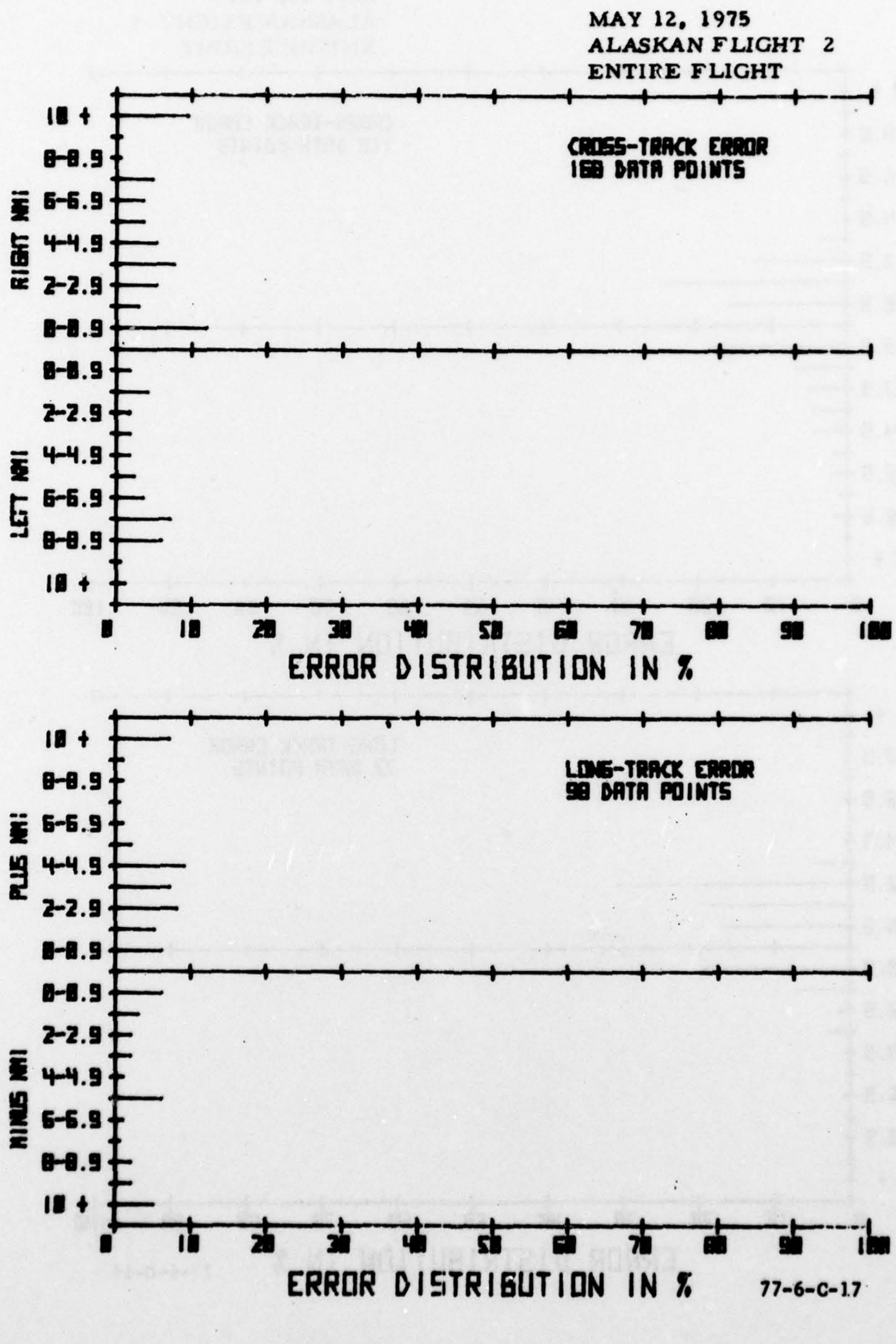
MAY 10, 1975
ALASKAN FLIGHT 1
ENTIRE FLIGHT





77-6-C-16

71

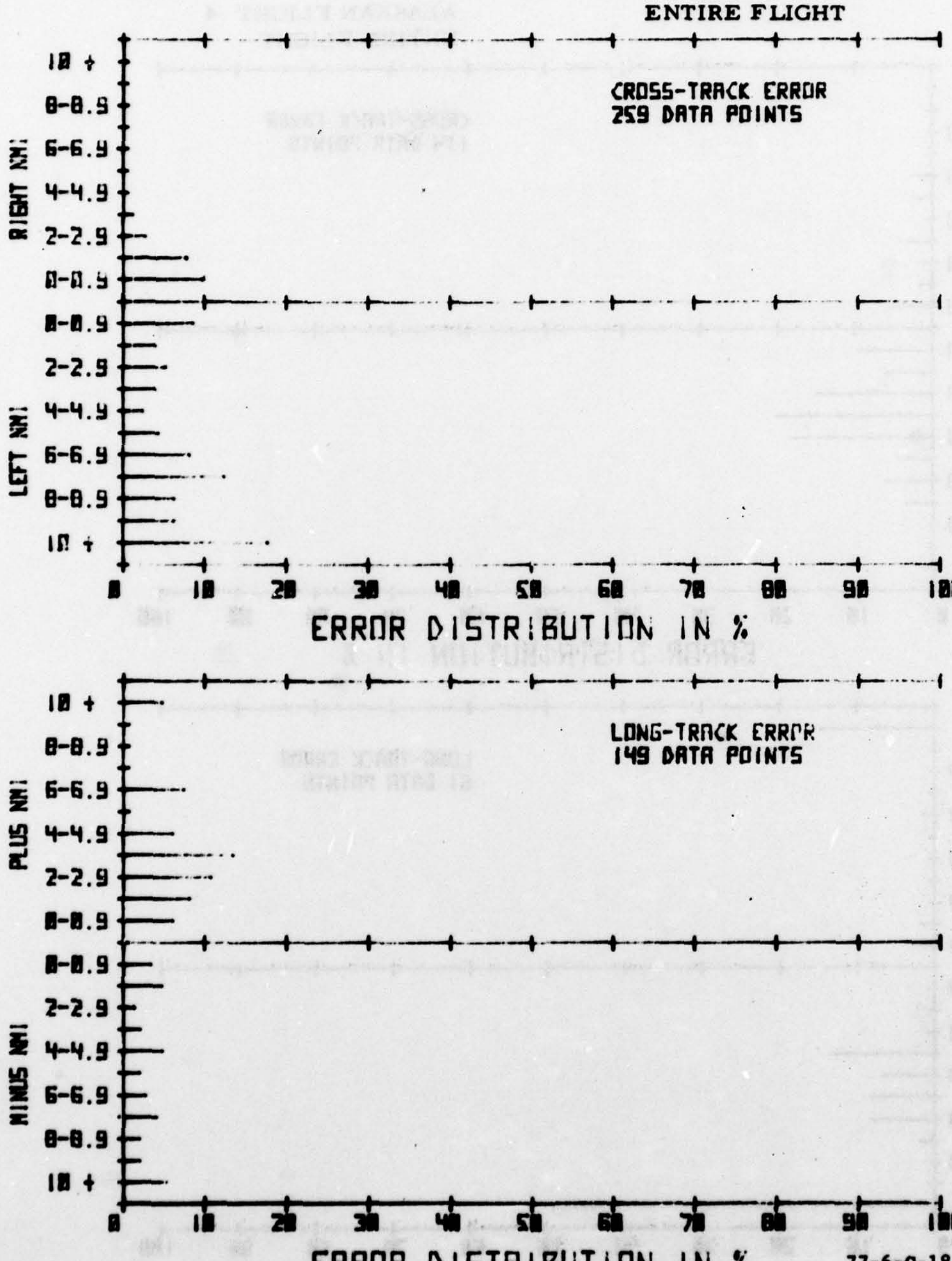


MAY 12, 1975
ALASKAN FLIGHT 2
ENTIRE FLIGHT
CROSS-TRACK ERROR
100 DATA POINTS
RIGHT NMI
LEFT NMI
10 +
8-8.9
6-6.9
4-4.9
2-2.9
0-0.9
0 10 20 30 40 50 60 70 80 90 100
ERROR DISTRIBUTION IN %
LONG-TRACK ERROR
90 DATA POINTS
PLUS NMI
MINUS NMI
ERROR DISTRIBUTION IN %

77-6-C-17

72

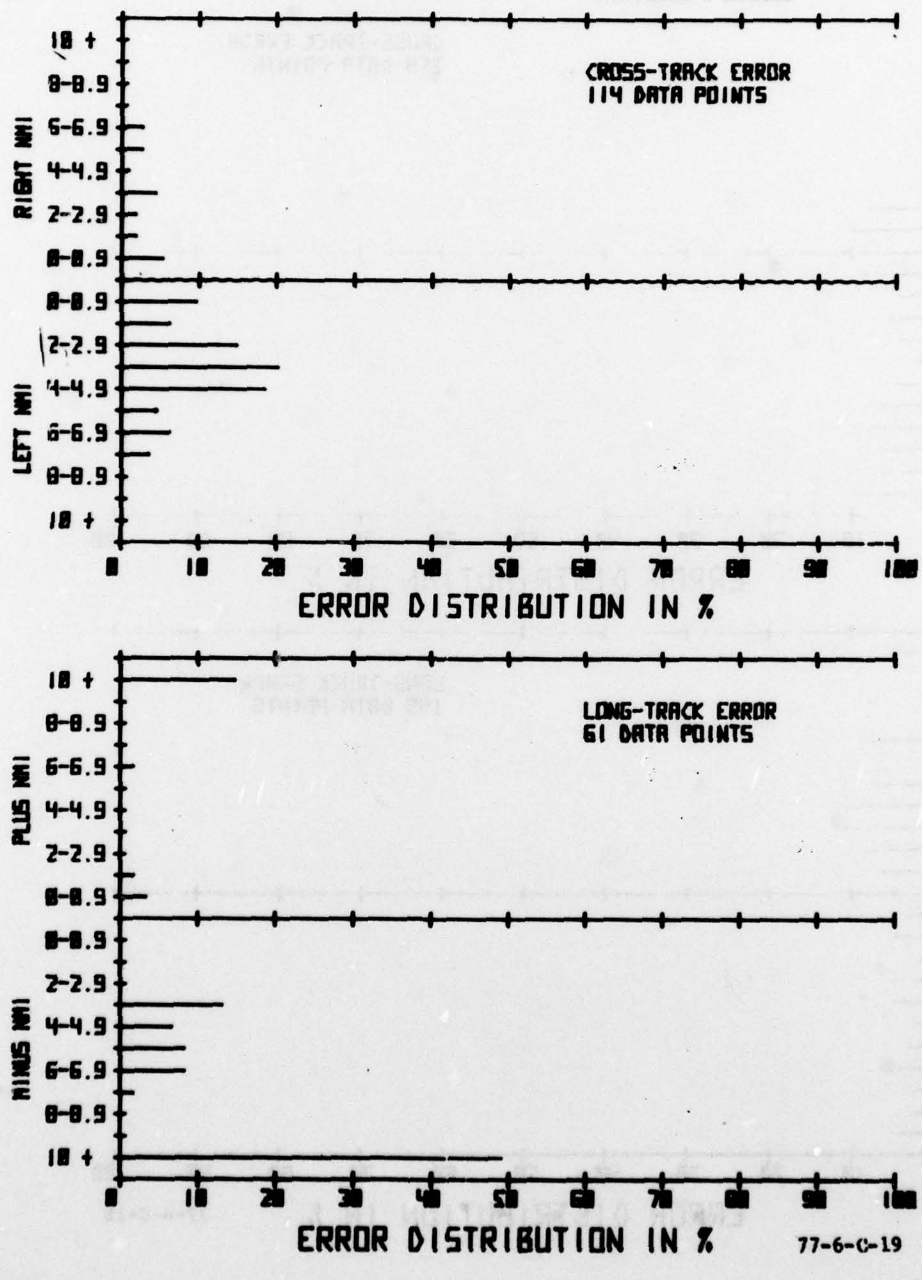
MAY 13, 1975
ALASKAN FLIGHT 3
ENTIRE FLIGHT



77-6-C-18

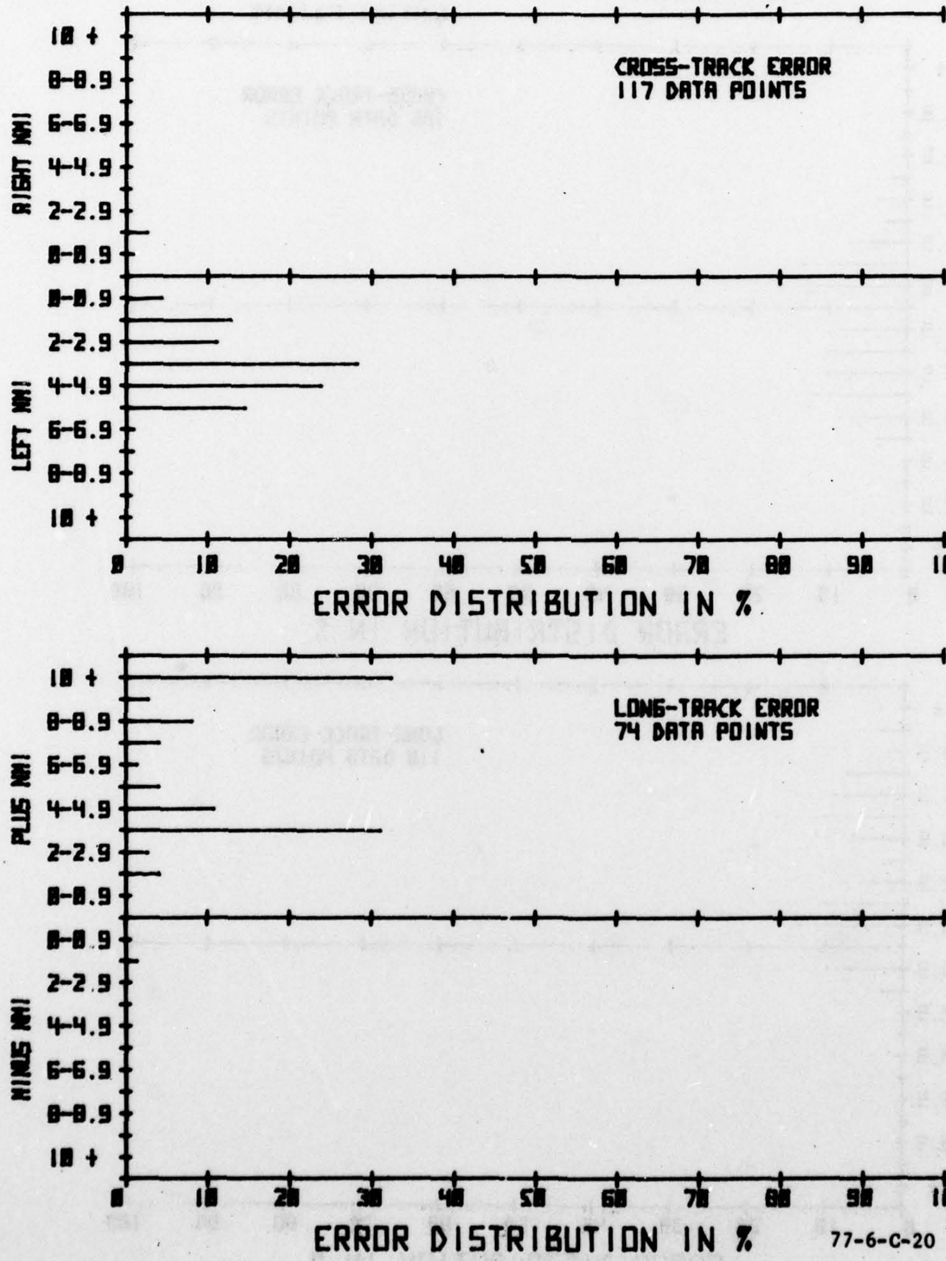
73

MAY 15, 1975
ALASKAN FLIGHT 4
ENTIRE FLIGHT

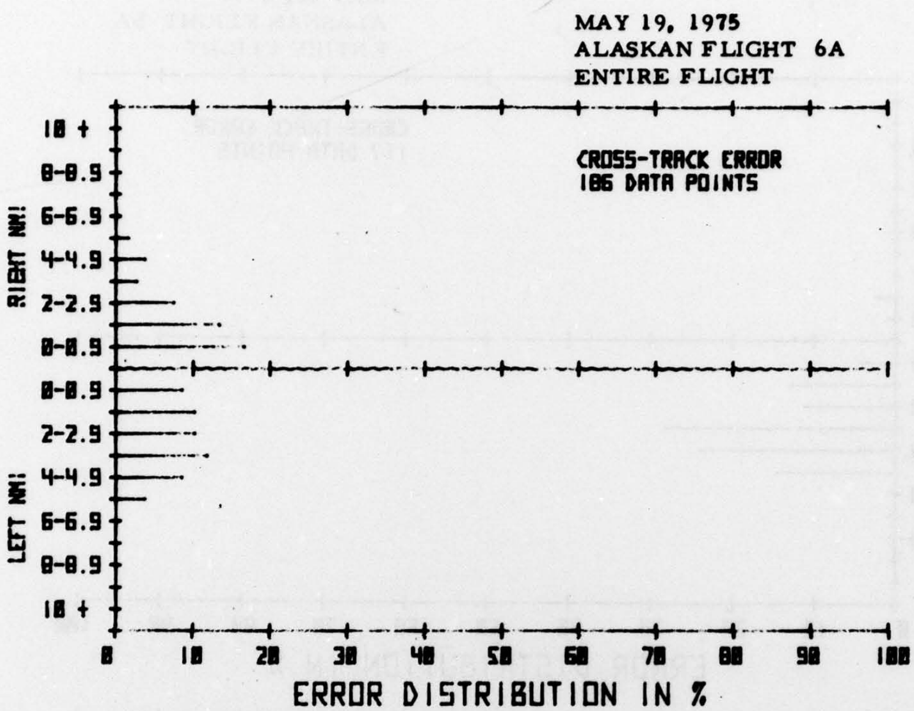


77-6-C-19

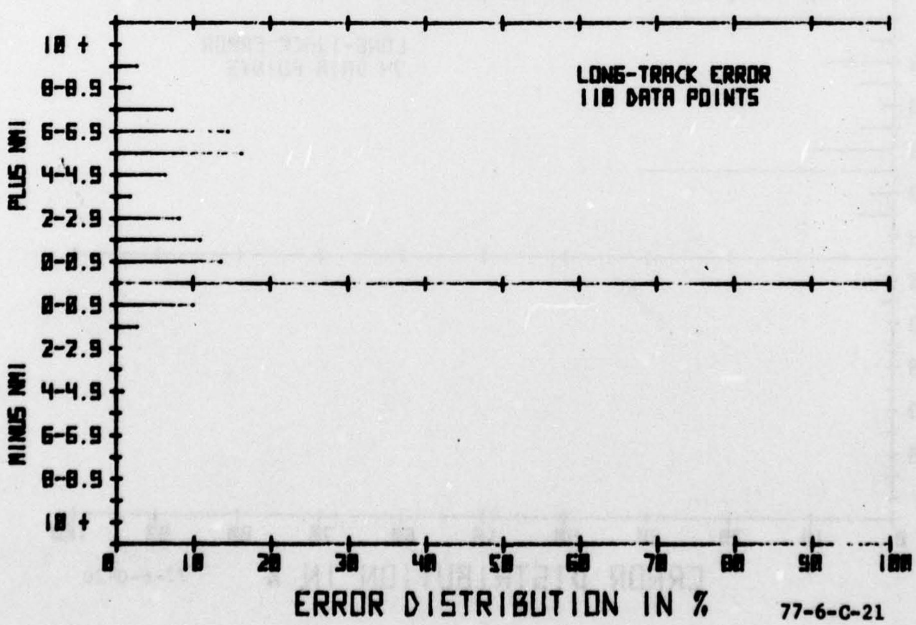
MAY 16, 1975
ALASKAN FLIGHT 5A
ENTIRE FLIGHT



77-6-C-20



MAY 19, 1975
ALASKAN FLIGHT 6A
ENTIRE FLIGHT
CROSS-TRACK ERROR
106 DATA POINTS
RIGHT NM
LEFT NM
10 +
8-8.9
6-6.9
4-4.9
2-2.9
0-0.9
0 10 20 30 40 50 60 70 80 90 100
ERROR DISTRIBUTION IN %



LONG-TRACK ERROR
110 DATA POINTS
PLUS NM
MINUS NM
10 +
8-8.9
6-6.9
4-4.9
2-2.9
0-0.9
0 10 20 30 40 50 60 70 80 90 100
ERROR DISTRIBUTION IN %

77-6-C-21

76